Hydrokinetics in Alaska

Lessons Learned from the Alaska Power & Telephone Eagle Hydrokinetics Demonstration Project

Prepared for:

The Denali Commission

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Final – December 2013

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Introduction

Rural Alaskans pay some of the highest energy prices in the United States. In most rural Alaska communities, electricity is produced with diesel electric generators, which rely on expensive diesel fuel shipped to the community, often only once or twice a year. Alternative and renewable sources of energy are being explored around the state in an effort to stabilize costs, localize energy production, and create viable long-term communities.

Hydrokinetic technology, a pre-commercial technology, could be an important source of renewable energy for many Alaska communities located near rivers. Alaska is estimated to contain approximately 40% of the total U.S. river energy resource (*Johnson and Pride)*. In contrast to hydroelectric technology, which produces electricity using the gravitational force of falling or flowing water, hydrokinetic technology generates electricity directly from the natural flow of water. Traditional hydroelectric projects require damming or diverting water; while implementing a hydroelectric project in rural Alaska is usually impractical for environmental and economic reasons, a hydrokinetics project may be viable.

Generating electricity using hydrokinetics holds great promise; however, the technology is still maturing. This report discusses an "in-river" hydrokinetic turbine demonstration project in Eagle, Alaska, in the summer of 2010. A partnership project between Alaska Power & Telephone (APT) and the Denali Commission, this turbine project exhibited both the successful power generating capacity of this technology and some of the significant challenges that must be addressed for it to realize its full potential.

This report is organized as follows:

Background Information for Hydrokinetics provides an explanation of the hydrokinetic resource and an overview of the principles of hydrokinetic systems, including information on their potential applications and the current state of the technology.

Eagle Hydrokinetic Demonstration Project Summary, the body of this report, discusses the hydrokinetic project at Eagle, Alaska, which culminated in turbine deployment during the summer of 2010. This summary provides information on the Eagle community; the various institutions involved in the project; an explanation of the river surveys and resource assessment; the selection and design of the hydrokinetic turbine; the engineering of the complete system, including the anchoring, transmission, and integration components; the permitting process for the turbine site; and the environmental studies accompanying the project. This section also provides a narrative overview of the installation process and the turbine performance during the summer of 2010.

Lessons Learned discusses the important lessons learned from the most difficult aspects of the Eagle project. It reflects on the experience of the turbine deployment at Eagle, highlighting some of the most significant obstacles to the success of this project.

Finally, **Moving Forward** makes suggestions for encouraging the maturation of this hydrokinetic technology, incorporating the lessons learned from Eagle to make recommendations for the successful development of these turbines.

For further information on this report, please visit http://acep.uaf.edu.

Background Information for Hydrokinetics

The idea of using some form of water to generate energy is nothing new. In fact, since its inception more than 2,000 years ago, hydropower in different forms has been used to fill various power needs (*History*). Conventional hydropower's appeal, namely its reliability and stable energy costs, has led to its wide adoption. In 2003, more than 60,000 MW of conventional hydropower supplied around 10% of the United States' total electricity. In Alaska, this percentage is even higher, with hydroelectricity filling between 17% and 24% of the state's electricity demand in 2009 (*Atlas 10, Statistics 8*).

These conventional hydropower resources tend to involve larger projects that either impound or divert water to take advantage of its potential energy by channeling it through turbines that rotate generators. While large hydropower projects can generate a lot of energy, they can be (1) very expensive, requiring intensive material and construction and/or (2) environmentally and ecologically damaging, as they often disrupt normal river flow and can negatively impact fish and other populations either by impeding natural migration patterns of important anadromous species or by altering the aquatic habitat that species require.

Hydrokinetic technology could offer a way to take advantage of the unique resource that Alaska rivers provide. For communities with smaller electrical needs, the scale of hydrokinetic turbines may, in fact, be more appropriate. An advantage of these smaller hydropower projects is their use in place of conventional impounding/diverging techniques where the scale of larger projects is impractical. For example, the Golden Valley Electrical Association conducted several site studies on the Tanana River southeast of Fairbanks and concluded that the scale necessary for intensive hydropower projects was either technically, economically, or environmentally unfeasible (*Tanana Reconnaissance*). Another study, near Healy, found that conventional hydropower or run-of-river projects were similarly impractical given the available river resource (*Healy Reconnaissance*).

Scale is only one of the reasons that hydrokinetic technology may be more suitable for some communities. It could also reduce the negative impact of energy extraction on the river ecology and aquatic habitats. Generating hydrokinetic power differs from generating conventional hydropower in that it does not require large change to or manipulation of river flow; rather, it harnesses energy from flowing water. More conventional technologies like dams or weirs interrupt the environment and can lead to detrimental impedance of fish and manipulation of river habitat.

Principles

Hydrokinetic technology generates electricity directly from the natural flow of water. Hydrokinetic technologies can be characterized by how the water flows across the axis of rotation or otherwise interacts with the technology. Such characterizations include cross flow (water flowing across the axis of rotation), axial flow (water flowing parallel to axis of rotation), and vortex-induced vibrations. Another distinction between different hydrokinetic technologies is how the system is mounted and secured; some are designed to be completely submerged and secured to the river bottom, while others are deployed off a barge and float near the surface, anchored or tethered in place.

Regardless of their specifications, all hydrokinetic turbines operate on the general idea of extracting part of a current's kinetic energy and converting it into usable, transmittable electricity. Somewhat like a conventional dam in the technical conversion of energy, these turbines convert kinetic energy (moving water through a turbine) into electrical energy (the turbine, connected by a driveshaft, powers a generator). The major difference is that conventional hydropower technologies manipulate (through impoundment or diversion) the water used to power the turbine/generator, while hydrokinetic extraction allows the water to flow freely through the turbine, using only the natural current to generate electricity.

Hydrokinetic energy extraction works off of the same idea as wind energy technology. That is, both are based on the principle that extractable power is essentially a function of the mass flow (of water or air) moving through a given area over a given time. The power of such a mass is expressed in the simplified equation:

$$Power = \frac{1}{2} Area * Density * Velocity^3$$

Area refers to the turbine area across which the current flows, density refers to the density of the water, and velocity is the speed of the current. Like wind turbines, hydrokinetic turbines operate best at certain speeds, which generally range from 2–7 knots (1–3.5 m/s) (*Johnson and Pride*). Optimal energy extraction usually requires 5–7 knots (2.6–3.6 m/s), and since power is a function of the current cubed, current velocity one of the most important factors in locating hydrokinetic potential. An ideal hydrokinetic turbine site has both sufficient and steady current, with ample and consistent speed. Additionally, for turbines of a given size (with an area that factors into the power equation), river depth and width are also significant considerations when siting a hydrokinetic project, since they define the cross-sectional area over which energy can be extracted. Localized issues such as turbulence, seasonal flow rate and water levels, and resource availability also determine the available energy.

Technology Development Outcomes & Challenges

In-river hydrokinetic turbines could be a clean, reliable alternative to diesel generators, the current source of electricity in most of rural Alaska. Their potential to provide the reliability of hydropower while offsetting or replacing fossil fuel makes these technologies attractive, but they are still at a relatively undeveloped stage. Hydrokinetic potential has been identified and explored with the deployment of several projects in Alaska, and several others in the continental U.S. and Canada. The following is a summary of key hydrokinetic projects in Alaska to date:

- Ruby - The project at Ruby consisted of a vertical axis, 5-kW New Energy Corporation EnCurrent turbine deployed in the summer of 2008 by the Yukon River Inter-Tribal Watershed Council. The project operated during ice-free months from a moored barge with a submerged power cable transmitting electricity to shore. However, significant issues arose during deployment; extensive damage to the power cable occurred and large amounts of debris obstructed the turbine, resulting in less than 200 kWh of electricity being generated. A debris boom designed to deflect surface debris was installed on the barge; however, logs and branches continued to accumulate, posing a risk of damage to the device and requiring workers to clear the debris. The Ruby hydrokinetic project was terminated after the summer of 2010, when unusual amounts of debris prevented long-term deployment of the turbine. Of note, the project provided electricity to the Ruby power grid in 2009, making it the first successful deployment of in-river hydrokinetic technology in the United States.
- Nenana - The Alaska Hydrokinetic Energy Research Center (AHERC) has been developing a test site located on the Tanana River in Nenana. Researchers use the test site to define ways hydrokinetic turbines and aspects of the river interact, including fish, debris, sediment transport, and icing. Preliminary work has included site and environmental assessments for permitting.

These projects were the collaborative effort of a number of interest groups and have shed light on some of the most important challenges facing the continued development and success of this pre-commercial technology. These challenges can be broadly described as a function of either environmental interaction, technical operation, or some combination of the two and include (*Hirsch and Worthington*):

- access to optimal currents/generation potential
- adequate, sturdy anchoring
- transmission and integration to grid/shore/existing utility structure
- river debris, sediment load and/or buildup
- ice formation and breakup
- fish-turbine interaction
- permitting
- operation and maintenance requirements

As hydrokinetic research has progressed in the Alaska environment, it has become clear that one of the biggest obstacles to further development and commercialization of the technology is mitigating the effects of river debris. Fine particulates such as silt or sediment, common in many glacial-fed rivers in Alaska, can interfere with the moving parts of the turbine. Larger debris such as logs or branches can directly strike the turbine, causing damage, or accumulate and increase and focus the force of the river. Accumulated debris also disrupts the flow of water, leading to decreased power outputs.

Because rivers play an important role in the environment and economy of the state and country, regulations are placed on structures in and near waterways to ensure the safety of other structures, boats, and the local and downstream environment. However, there are no regulations that specifically address hydrokinetic devices, and the permitting process is not streamlined or tailored to this technology, which can lead to costly delays. In addition, information needed for permitting is often only available from the experience of river deployments (a chicken-and-egg conundrum). These issues and others are challenges that the permitting community, state, and technology developers are currently working through, with some success.

There is little known about device-specific interactions with the riverine environment since there have been few deployments of hydrokinetic technologies. As mentioned above, this lack of information is often critical to permit applications and monitoring plans. There has been concern that hydrokinetic devices may negatively interfere with fish populations. For example, juvenile fish are extremely susceptible to pressure differentials; significant pressure drops across a turbine may rupture their swim bladders and kill them. In addition, the effects of hydrokinetic devices on downstream sedimentation and riverbed dynamics are not well understood. These information gaps and others are currently being addressed by demonstration projects and the research community alike. Detailed fish studies, such as those incorporated into the Eagle project, provide important information on fish populations and habits that can inform turbine placement, operation, and permitting.

The challenges of deployment and operation of a hydrokinetic device in a remote Alaska community present another barrier to future adoption of the technology. Swift river currents, debris, and limited infrastructure, such as heavy equipment, docks, and cranes, are issues that technology developers are seeking to address through research and design. After a hydrokinetic device is in place, operators on land must be able to receive the generated power and monitor the conditions of the device. Communication and power transmission cables must be laid across the riverbed in a way that minimizes damage to the cables, the device, and the environment. System anchoring is a particular challenge that technology developers are working through. Issues such as how to deploy anchors in rural locations, the interaction of anchoring lines with debris, and the economics and feasibility of in-river pile placement are all being explored.

The significance of each challenge can vary from site to site. Stakeholder acceptance is of immense importance and might depend on any number of factors, including the reliability, power, generating capacity, and economic or environmental costs of the turbines. Overcoming these challenges—by developing a reliable, flexible technology that can be tailored to mitigate the specific hurdles that arise at a given project—while gaining stakeholder support will be crucial in advancing hydrokinetic in-river turbines to a mature, readily deployable technology.

The Eagle project showed that hydrokinetic turbines can be successful in principle, but it also highlighted a number of significant challenges, including the vulnerability of these devices to river debris. Many challenges may be inherent given the nature of the turbines and the environment in which they operate. It is hoped that the lessons learned from testing the turbine at Eagle can educate researchers and equip them to deal with these challenges on the road towards the commercialization and success of hydrokinetic technology.

Eagle Hydrokinetic Demonstration Project Summary

As a technology that could eventually be employed by rural communities across the state to reduce energy cost and dependence on fossil fuels, hydrokinetic turbines have attracted the attention of the Denali Commission and other groups involved in Alaska's energy industry and rural communities. In 2010, APT deployed a 25-kW New Energy Corporation EnCurrent hydrokinetic turbine on the Yukon River at Eagle, Alaska. As one of the Denali Commission's "distressed" communities,[1] with a relatively high unemployment rate (14%) and significant population below the poverty line (16.5%), the town of Eagle seemed like an appropriate site to test this promising technology, which could reduce electricity prices and serve as a boon to industry (*Pilot Application*).

Community Profile

Eagle (including the nearby community of Eagle Village) is a rural Interior city located on the Yukon River with a population of less than 150. A remote community, Eagle is seasonally accessible by road (via the Taylor Highway during summer months). Flights from Fairbanks and Tok into a nearby state-owned gravel airstrip provide transportation to the city year-round (*Community Database*).

Like other isolated rural communities within the state, Eagle relies entirely on diesel generators for electricity; APT is the electric utility for Eagle. A hydrokinetic turbine in the nearby Yukon River, which has been identified as a promising hydrokinetic resource, could be an alternative source of electricity. APT spearheaded the turbine project as an investigation into the potential of hydrokinetic power to displace

[1] The Denali Commission utilizes an annual, updated list of distressed communities prepared by the Alaska Department of Labor and Workforce Development (DOL&WD), Research and Analysis Section, using the most current population, employment and earnings data available to identify those Alaska communities considered "distressed". The distressed status is determined by comparing average income of a community to full-time minimum wage earnings, the percentage of the population earning greater than full-time minimum wage earnings and a measure of the percentage of the population engaged in year-round wage and salary employment.

diesel in meeting Eagle's electricity load demands, which range from 70 kW to 150 kW, and for reducing the cost of electricity to these consumers.

Project Partners

The Eagle Hydrokinetic Project received funding through the Denali Commission Emerging Energy Technology Grant (EETG) program[2] for a five-year study of multiple aspects of a hydrokinetic turbine, including technical performance and the potential environmental/ecological implications (*Johnson and Pride*). The Denali Commission considered this $1.6 million grant as an investigation into the broader potential for hydrokinetic technology across the state. Both APT and the Denali Commission recognized the usefulness of the Eagle test site as an opportunity to explore factors that stand to affect the maturation of this pre-commercial technology, "including environmental interaction, performance and efficiency, deployment challenges, support design, debris avoidance, and economics" (*Yukon River Hydrokinetics*).

The Alaska Center for Energy and Power (ACEP), an applied energy research group within the Institute for Northern Engineering at the University of Alaska Fairbanks, served as the program manager of the EETG program on behalf of the Denali Commission. In addition, ACEP provided independent project and performance analysis and reporting. This report is the final product of that effort.

APT began exploring the idea of a hydrokinetic turbine at Eagle in the mid-1990s, when the firm replaced the previous utility company in Eagle. The previous utility owner had been developing a project with the Underwater Electric Kite Corporation (UEK), a partnership that APT resumed. As the utility provider for Eagle, APT was interested in pursuing hydrokinetic turbines as a method of offsetting its diesel requirements and service costs. However, this first effort in the 1990s was discontinued. In 2006, the original partnership with UEK was renewed and, with funding from the Commission, the project began moving forward once again (*Beste Interview*).

UEK, headquartered in Annapolis, Maryland, agreed to provide a horizontal axis turbine for the Eagle site based on an initial design produced during the mid-1990s but with modifications that had been developed since that time. Clifton Labs from Seattle, Washington, was contracted to design the UEK turbine's grid integration to incorporate electricity produced by the device into Eagle's existing utility structure.

Due to the passing of key personnel at UEK, however, a new turbine supplier was unexpectedly needed for the project. At the beginning of 2009, APT contracted with New Energy Corporation to supply a vertical axis turbine (a larger version of the New Energy Corporation turbine deployed at Ruby). ABS Alaska, the Alaska distributor of the New Energy Corporation turbine, designed and built the deployment system and provided maintenance equipment and personnel. Additionally, when APT terminated its UEK contract, ABS took over responsibility from Clifton Labs for engineering and building the turbine transmission and integration system.

APT also partnered with several firms to complete the various site studies required for the implementation of a hydrokinetic turbine in the Yukon River. TerraSond of Palmer, Alaska, performed a number of river surveys, including bathymetric, discharge, velocity and sub-bottom profiles, gathering data for determining optimal turbine placement and power generation potential and engineering the

[2] The funding goal of the EETG program is to develop emerging energy technology that has the potential of widespread deployment in Alaska and has the long-term goal of reducing energy costs for Alaskans.

anchoring system. For the study on fish population and migration and fish-turbine interaction in Eagle, APT contracted with BioSonics, a hydroacoustic equipment, data collection, and monitoring firm; the University of Alaska Fairbanks School of Fisheries and Ocean Sciences (SFOS) performed monitoring and collection activities as part of the fish studies throughout the lifespan of the project.

Resource and Site Characterization

Performance of a hydrokinetic turbine depends not only on the available resource but also on the interaction between the technology and the resource environment. A fast-flowing river can be a valuable source of renewable energy, but without a turbine designed to operate in a unique river environment such a resource may remain undeveloped. To develop a turbine system able to operate successfully along the specific stretch of the Yukon River near Eagle, APT first commissioned a site assessment to inform the placement, design, and operation of the eventual system. The site assessment focused on generating a complete physical profile of the river site, including river depth, bottom topography, sediment movement, current velocity, flow and sub-bottom profiles, and riverbed characteristics.

TerraSond carried out the first site assessment from September 7–13, 2007. The bathymetric survey looked at the river channel shape and bottom topography. Specifically, the survey charted the river thalweg—the continuous line that runs along the deepest parts of a river channel—an important feature in determining optimal turbine siting. TerraSond also determined flow (cubic feet per second) and velocity (meters per second) profiles. For the velocity profile, velocity was measured at various river depths. These values ranged from "1.5 m/s at 1.0 meters from the river bottom to 2.5 m/s at 0.5 meters below the surface," suggesting that the best turbine placement would be closer to the surface of the river than was initially anticipated or planned (*TerraSond*). This 2.5 m/s current was close to the ideal 5–7 knot range (2.6–3.6 m/s), for optimal hydrokinetic turbine output.

The river flow, characterized by a discharge profile, was measured on September 11 and 14 and matched the U.S. Geological Survey (USGS) values to 99% (*TerraSond*). The USGS record of flow volumes supported seasonal deployment, with significant flow beginning in May and continuing through September. APT determined that "in addition to the hazards of winter conditions (such as ice formation, frozen debris, and frazil ice), river flow velocity is too low during the winter to make operations economical based on the characteristics of this turbine and the operating environment" (*TerraSond 14*). The conclusion that "the project will likely only operate about five months (May–September) of the year" meant that, at least in the demonstration phase, the communities would still be heavily reliant on diesel-generated electricity for the majority of the year (*TerraSond 14*).

River surveys also gathered information about river topography, structure, and physical composition. The river shore was found to be mainly composed of silt and the bottom was found to be mostly composed of some silts and cobble-sized rocks. Information on the river bottom composition influenced APT's design of the turbine anchoring system, which addressed the fact that "obstructions were interpreted to be boulders and could impede piling, anchoring placement, and turbine safety" (*TerraSond*).

Several other key environmental factors were noted during project design, including debris, sediment load, ice formation and breakup, and turbulence. Summary information regarding these factors is as follows:

Sediment Load

Heavy river sediment can impact the integrity of a turbine system because it may "abrade engineering components and sediment deposition or scour around anchors or foundations [affecting] their performance" (*International Water Power*). Because conditions in the Yukon River at Eagle change drastically according to seasonal freezing and thawing, "95 percent of all the sediment discharged during an average year is moved during the months of May through September" (*USGS*).

Turbidity

Characterizing the site during 2008, APT noted that the "Yukon River in the area of the City of Eagle poses several challenges, including high current velocities and high turbidity" (*2nd Quarter 2008*). Though precise measurements were difficult in the fast-flowing river setting, the eventual turbine output ended up being significantly less than the rated 25 kW; turbidity in this real-world application could have contributed to the reduced efficiency of the device, causing a discrepancy from ideal performance potential (Beste).

Figure 1: The arrow shows direction of current flow on the Yukon (note the anchored system barge directly above the arrow); the solid line represents approximate area prone to ice jams.

Ice Breakup

The geography of the river at Eagle makes this site particularly susceptible to the effects of ice breakup. Figure 1 shows the island at the center of the river near the site selected for the turbine and the narrower bend in the river upstream of this site. This bend also features an upward sloping riverbank. During spring breakup, ice jams have been known to form in this area, an occurrence that the TerraSond study characterized as an “irregular and catastrophic process which presents as a chaotic system of variables.” Indeed, while chunks of ice can collide with or physically damage the turbine, the more systemic effects of ice breakup, including the consequences of these ice jams, can also pose a significant challenge to turbine deployment and operation.

For cold climate regions like Alaska, “river ice breakup [can be] the most significant hydrologic event of the year, producing water velocities and levels that far exceed those produced by equivalent discharge under open-water conditions” (*Forecast*). When ice jams form during breakup they can obstruct river flow, which leads to flooding and can damage river habitats, erode riverbanks, and destroy property and infrastructure in nearby communities. The flooding caused by ice jams is responsible for more than $100 million dollars in damage every year in the United States (*U.S. Army CoE*).

Debris

Unfortunately, some of those characteristics of the river environment that make it attractive as a potential energy resource can cause serious problems. Accessing fast currents means exposure to debris, which can make operation and maintenance of the turbine system more difficult.

Debris can affect turbine performance by either (1) colliding with and damaging the turbine itself, thus preventing or interrupting operation, or (2) accumulating on other parts of the system, including the deployment equipment, and endangering the system’s structure and functionality. These two dangers are similar to the risks associated with ice, which can also directly damage the turbine or compromise the soundness of the structures; but whereas in the case of ice, seasonal placement of the turbine can avoid many of these problems, strategic timing of deployment cannot easily avoid the problems associated with debris.

Debris poses one of the biggest challenges to hydrokinetic turbines becoming a mature, widespread application, and mitigation strategies have been employed with varying degrees of success. In the interest of characterizing the obstacle to hydrokinetic technology posed by river debris, a report prepared by ACEP in April 2011 for the Ocean Renewable Power Company discusses “examples of efforts to protect other engineered riverine structures” and “the mechanisms for how debris enters the flow and is transported downstream” (*Tyler*). The report discusses techniques for dealing with debris, including “treibholzfange” detention devices (V-shaped structures placed/driven into the river), debris booms, fins/posts (mainly used for bridges), sweepers, deflectors (protective grates), and trash racks. For larger hydropower installations, trash racks are a popular method of buffering the impact of debris. But trash racks require intense maintenance, which, while feasible when part of a larger hydropower project or dam, are impractical for smaller-scale turbines. The installation at Ruby used a diversion boom to deflect surface debris away from the turbine system. While this boom was practical given the size of the turbine barge it was designed for, it was not successful at deflecting the volumes of debris encountered.

Figure 2: The first debris mitigation strategy at Eagle was comprised of wooden and metal diversion boom

The team at Eagle expected some challenge from debris, but did not anticipate the magnitude of the drift events on the Yukon. The initial debris mitigation strategy employed a large, triangular projection—a diverting boom like that used at Ruby—on the front of the turbine barge. This was essentially a scaled-up version of the one used in Ruby, designed to deflect surface debris to the sides of the device and prevent collision between debris and the turbine equipment.

Permitting

A number of state and federal agencies exercise regulatory oversight on this type of energy project. For the Eagle project, these groups included the Federal Energy Regulatory Commission (FERC), the Army Corps of Engineers (CoE), the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Services (NMFS), the U.S. Coast Guard, the Alaska Department of Fish and Game (ADF&G), and the Alaska Department of Natural Resources (DNR). Many of the permit applications were submitted several years before the EETG grant was awarded to APT; many licenses and permits were awarded in 2002-2003 due to APT's project develop efforts in the mid-1990s, and only required renewal or extension by the time APT was prepared to install the device.

FERC serves as the regulating agency for all hydropower installations, federal and non-federal, in the United States. As a small hydropower technology, hydrokinetic turbines fall under FERC purview for licensing and permitting. At the beginning of 2008, APT submitted a pilot project license application for the project to FERC. This pilot project license is one of several types of licenses and/or permits administered by FERC and apply to hydrokinetic applications that are:

- Small (less than 5 MW)

- Short-term (less than five years and removed before the end of the license term)
- Located in an area approved as not "sensitive" by FERC review and also based on stakeholder comments
- Able to be removed or shut down quickly if necessary, with full test site restoration
- Have the required information on environmental study, monitoring and/or analysis with proof of measures for "safeguarding the public and environmental resources" (*FERC 5*)

FERC introduced this "pilot project license" in an attempt to streamline the development of hydrokinetic energy technology. Other hydropower projects, like dams, require 30- to 50-year licenses because they are long-term, high-impact installations; hydrokinetic projects, on the other hand, are currently much smaller in scale and operational life. FERC grants pilot permits to "to test new, hydrokinetic technology devices; to determine the appropriate sites for hydrokinetic projects; and to gather information on environmental and other effects of the devices" (*FERC Pilot*).

APT was able to proceed with the Eagle turbine project while the pilot permit application was under review through a FERC preliminary permit. A preliminary hydropower permit "does not authorize construction; rather, it maintains priority of application for license (i.e., guaranteed first-to-file status) while the permittee studies the site and prepares to apply for a license" (*FERC Preliminary*). With the preliminary permit acquired and the pilot permit filed, APT was able to move forward with the turbine project based on a precedent set by Verdant Power in New York City's Roosevelt Island Tidal Energy project.[3]

APT also applied for project permitting through the CoE. The CoE permit, issued initially in 2003, required a research and monitoring plan "assessing possible injury to fish associated with the turbine operation, pressure changes caused by blade action, heat generation by the unit and possible changes in surrounding water temperatures, and the physical, biological, and behavioral impacts to different sizes of fish (larval, juvenile and adult)" (*Pilot Application 74*). This environmental research and monitoring was subject to review and approval by the USFWS and ADF&G. The CoE emphasized the importance of minimizing both in-river and on-shore environmental impacts of the turbine. The U.S. Coast Guard also exercises oversight on projects within the waterway. The Coast Guard "determine[s] if the installation will pose potential adverse impacts to the users of the waterway" and whether Private Aids to Navigation, including lights and signage, are necessary for a given renewable energy installation (*USCG*).

Because the Yukon River drainage area is a designated "essential fish habitat," the CoE permit was also subject to environmental review by NMFS. NMFS advised that environmental studies should be conducted with particular sensitivity towards the effect of the turbine on salmonid juveniles and recommended methods of monitoring, including "hydroacoustics, net sampling and diving (visual observation)" (*Pilot Application 195*).

Two divisions within DNR—the Office of Habitat Management and Permitting (OHMP) and the Division of Mining, Land and Water—also exercised oversight on the Eagle project.

[3] This project was installed under a preliminary permit from FERC with the stipulation that generated power would be supplied only to a local grocery store and not to the state or national grid (*Martin*). APT was able to use this precedent for the initial phase of the Eagle turbine before deciding whether or not to permanently install the system. (*Martin*).

The OHMP issued a Fish Habitat Permit in the early stages of the Eagle project on August 16, 2002, which required renewal through December 31, 2011, for the actual installation of the turbine. The permit required that APT submit a communication/power cable installation plan to ADF&G, providing evidence "substantiating [that] the reported pressure drops across the turbine" were not harmful to fish, and implement an underwater monitoring program tracking fish response to the turbine (*Pilot Application 76*).

The Division of Mining, Land and Water granted APT a right-of-way permit and easement for the proposed turbine site. The permission was accompanied by a number of stipulations, including that "prior to any construction or development that will use, divert, obstruct, pollute, or utilize any of the waters of the State, the grantee shall first obtain approval therefore from the Commissioner of the Department of Fish and Game," and that the turbine could not unduly impinge upon the public use of the river for "navigation, commerce, fishing, and other purposes" (*Pilot Application 177, 83*). A special stipulation emphasized the preservation of the Yukon as a critical fish resource and required that APT "conduct studies to determine the effects of this turbine on salmon as requested by the National Marine Fisheries Service. If unacceptable adverse impacts to salmon are observed and remain unmitigated after operational, seasonal, or design changes are implemented, the authorization may be rescinded" (*Pilot Application 85*).

This permitting process, even with the Verdant Power precedent to ease the overall FERC requirements, demanded considerable time and effort. Though many of the application components—river site assessments, resource evaluation, construction plans, evaluation of potential impacts—were things APT already had to consider in the turbine development and deployment process, the permitting process added to the cost and time devoted to these assessments. The need to gather and assimilate this information for every individual turbine site could present permitting delays for future projects. Delays in the permitting process can have a significant effect on the completion of many types of energy projects, especially projects with newer technologies, which may require more extensive background research and environmental documentation before they can move forward.

Environmental/Fish Studies

Hydrokinetic turbines are an interactive energy technology. Developing this technology requires understanding the interaction between the turbines and their environments. Many of the physical hurdles to development involve the effect the environment has on the turbine; the river's velocity influences power production, turbulence and sediment load affect turbine efficiency, and debris can factor into turbine performance.

While the effect of the environment on turbines plays a significant role in the development of this technology, the turbine also affects the environment. Investigating the effect of the turbine on the environment is an important part of acquiring necessary licenses and permits and gaining critical stakeholder acceptance. For example, the turbine and barge at Eagle created bow wakes. This visible distortion of the river is one illustration of how a turbine might impact its environment. Though not necessarily destructive, this does suggest that there may be other significant and perhaps negative effects.

"River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska," an ACEP report on the state of hydrokinetic technologies, identified other potential impacts of a hydrokinetic turbine on the environment "related to water turbulence, corrosion, anchoring systems, fluid leaks (e.g., hydraulic fluids), underwater transmission line effects, and installation and maintenance problems" as well as the "potential ecological effects related to marine mammals and to marine and river fish" (*Johnson and Pride*). While hydrokinetic turbines could offer an energy resource with minimized impacts compared to other technologies (impoundment dams, for example) the environmental consequences of extracting energy from rivers with these turbines warrants continued exploration.

As mentioned above, permits and various agency approvals were largely contingent on the completion of the stipulated environmental studies. These studies were necessary for determining the potential effects of the turbine on important river habitats, but they also required extensive time and resources. The requisite environmental studies were mostly focused on the potential effect on fish populations. Because the Yukon River at Eagle and in much of Alaska had never before been the subject of such detailed environmental study, particularly with respect to fish populations, research and monitoring were extensive undertakings (*Bradley and Seitz 5*).

In Eagle, the potential adverse impact of the turbine on important fish communities represented a major environmental concern. Throughout the permitting process, various regulatory agencies emphasized the necessity of completing a thorough environmental analysis and monitoring study at the site. Indeed, the "proposed plans for monitoring, safeguarding the public and environmental resources" was a considerable component of the FERC pilot project permit application (*FERC 6*).

The Yukon River drainage area is an "essential fish habitat," a NMFS designation, and hosts a number of fish species that are of ecological and economic significance (*Olsen and Ricci*). These species include anadromous, migrating, and resident fishes, some of which are a vital resource for subsistence fishermen. Many Eagle residents participate in subsistence fishing along the river, which "consists primarily of gillnetting and fish wheels with some casting" (*Pilot Application 37*). In nearby Eagle Village, located just upriver from Eagle, residents also rely heavily on subsistence fishing, which provides "the majority of food items" for that community (*Pilot Application 40-41*).

Previous fish studies have investigated at least 19 fish species on the Upper Yukon River in Canada (*Bradford et al.*). These species include Pacific salmon varieties, notably Chinook and chum, both of which are among the more important commercial, subsistence, and aboriginal resources in Alaska. In Eagle, subsistence fishermen heavily depend upon these Chinook and chum salmon. Other species in the Yukon include a number of whitefish (*Coregoninae*) varieties as well as Arctic grayling. These species are ecologically important fishes that are also part of subsistence catches (*Ruby Monitoring*). The Yukon River salmon species are protected by the terms of the "Yukon River Salmon Agreement" between the United States and Canada.[4]

Prior to Eagle project, most of the extensive studies on Yukon River fish were limited to the Upper Yukon in Canada. In the interest of generating a body of knowledge on Alaska Yukon River fishes while investigating potential environment consequences from the turbines and fulfilling the mandated environmental study requirement, APT contracted with BioSonics and SFOS for this project. These groups conducted separate but complementary studies employing one or several of the recommended "measures to measure impacts of the river turbine [which] could include, but are not limited to, hydro-acoustics, net sampling, video-graphic documentation, and diving (visual observation)" (*Pilot Application 49*). Biosonics collected several sets of sonar data at the Eagle site starting in 2008; SFOS performed fish

[4] http://yukonriverpanel.com/salmon/wp-content/uploads/2009/02/yrs-agreement.pdf

catchment studies at various sites within the river to collect information on fish population composition and behavior. The SFOS study also collected data on a number of environmental variables to characterize river conditions and correlate them to fish presence and behavior (*Seitz Interview*).

BioSonics

BioSonics is a hydroacoustic equipment and services firm based in Seattle. The sonar equipment provided by BioSonics transmits and records the reflection of sonar energy waves within aquatic settings to detect the "presence or absence, abundance, distribution, size, and behavior of underwater plants and animals" (*Hydroacoustics*). Fish swimming by the sonar equipment—as well as other river-borne objects—reflect these sound waves, generating data sets that are then analyzed and interpreted.[5] The sonar equipment was situated upriver from the site to collect data on fish migration into the area of the turbine as part of a baseline study "to establish aquatic species composition, distribution, behavior and migratory patterns" (*Case Studies*). The BioSonics study was connected to data logging instrumentation on-shore by means of in-river power/communication cables.

The BioSonics study at Eagle was structured with two goals in mind, namely to "(1) understand fish behavior in this part of the river and (2) to consider the potential interactions between the turbines and the fish" (*Eagle Monitoring 1*). To establish a baseline for fish behavior, BioSonics sonar equipment was first installed at Eagle in 2008 to begin tracking the abundance and movement of objects within the river. The original plan also included installing a video monitoring system to get visual data that would complement the sonar data; however, low visibility in the Yukon precluded this part of the study (*4th Quarter 2009*). Instead, BioSonics installed "a remote sensing technology using a split-beam … as the most suitable monitoring method, due to volume coverage, continuous sampling, and unmanned operation" (*Eagle Monitoring 3*). This equipment was housed in a 400-pound steel mount, which was submerged and anchored to the riverbed near the eventual turbine deployment site, and was connected to an onshore computer station by power and communication cable. Data generated from the DT-X split-beam system was transmitted onshore to be stored in a set of hard drives. This split beam system was used to provide information on spatial fish location using 3-dimensional analysis techniques.

BioSonics equipment was employed again between June 3 and September 14, 2010, to monitor fish with the turbine in place. Measurements were taken during turbine deployment; however, the "selection, review and filtering" of this data was impacted by a number of factors (*Eagle Monitoring 9*). These factors included anchor/installation activity, boat traffic on the river, turbine raft deployment(s), turbine operation in the river, a number of "high wind and debris events," and a period from July 13–Aug 11 when the sonar mount was tipped over (*Eagle Monitoring 9*).

The collected data was analyzed to identify echoes that represented significant data points. These echoes were then matched to fish "tracks" or "traces" according to a set of parameters identifying and characterizing them as fish. The outcome of this process was a value of fish abundance called "flux," defined by the number of fish/m^2/hour. These measurements, however, were influenced by the presence of acoustic noise, the product of (1) sonar signals encountering both surface and bottom boundaries and (2) the interference of materials in the Yukon's "high suspended silt load" (*Eagle Monitoring 12*). Sonar

[5] Biosonics' sonar equipment had already been used beginning in 2006 for the study of hydrokinetic turbine/fish interactions for the Roosevelt Island Tidal Energy Project in New York City's East River.

waves encountering the bottom or surface might be reflected to the instrumentation, misrepresenting signals from these areas as fish. Heavy silt loads could have a similar effect on the collected data points. Additionally, the presence of debris both at the river surface and within the water column resulted in sonar beam reflection from these materials and added to the acoustic noise and made identifying fish difficult; the collected data had to be analyzed with this consideration in mind.

In addition to determining the abundance of fish, the collected data was used to generate estimates of fish size. Fish size estimates were made using a target strength analysis, which matches the strength of a reflected signal to fish size; however, target strength values could "not literally be converted to fish lengths, as the relatively high variability in the acoustic measurement may lead to inappropriate conclusions," and instead, served "as general guidelines" (*Eagle Monitoring 13*). The variability in acoustic measurement was increased by environmental variables including changes in river flow and river level, both of which affected the acoustic noise in the measurements. These flow and level changes affected the reflection of signals from both the water surface and the river's silt load.

Data was also used to generate information about the spatial distribution of fish, both horizontally and vertically, and the direction of fish movement within the river. This information was used to help understand potential impacts of turbines in various locations in the river and the corresponding fish patterns in those areas.

A number of conclusions on fish behavior in the Yukon near Eagle, including observations on fish movement up and downstream, were informed by BioSonics' data collection and analysis. For instance, upstream fish movement averaged 1.2 fish/hour; downstream movement was significantly higher, with an average of 5 fish/hour. Downstream fish movement consistently exceeded upstream movement across all data sets. Additionally, a vertical distribution analysis indicated that a "surface oriented turbine would intercept a much larger component of the population than a bottom mounted would" (*Eagle Monitoring 27).* This is relevant to the New Energy Turbine used at Eagle because it was deployed in the swiftest currents and at the top of the water column near the surface.

The behavior studies, however, failed to generate a "clear correlation between flux values and river flow" (*Eagle Monitoring 18*). That is, the understanding of fish behavior in response to various environmental factors remains incomplete. Additionally, although the studies of spatial distribution measurements of fish provided information on the potential impact of a hydrokinetic turbine at Eagle, they were unable to inform any decisive statements regarding observed or actual turbine impact on fish behaviors.

These BioSonics studies—the "acoustic monitoring equipment, data collection, and evaluation of the data [in determining] fish presence, their numbers, species and behaviors in the project area"—were a considerable project expense (*2nd Quarter 2008*). More than $246,000 was allocated for the BioSonics studies (*UAF contract*). This covered not only data collection and analysis, but the acoustic monitoring equipment. This equipment was vulnerable to the same river debris that jeopardized the turbine and deployment barge. Not only did the debris contaminate some of the sonar beam collection data, but it also interfered with the sonar equipment. Indeed, during the summer of 2010 "there were periods when the river bottom mounted sonar station was knocked over by the weight of debris that had collected on the mooring buoy line" (*3rd Quarter 2010*). The measurements from this period of 715 hours (more than a quarter of the 2,556 measurement hours) could not be used in the final study results. This data gap was significant.

In light of the vulnerability of this expensive equipment in long-term studies, it might be necessary to (1) reinforce the monitoring systems in future, which may mean added expense; (2) reassess their best use, comparing the merits of short- to long-term deployment; and (3) analyze the costs of such detailed studies in light of information gained, perhaps developing methods to reduce these costs where possible.

UAF School of Fisheries and Ocean Sciences

The SFOS assessment at Eagle was designed to understand "the species composition of the fish community and the ecology and river habitat utilization of each species … especially the spatial and temporal patterns of distribution for each species in the river channel" (*Bradley and Seitz*). By generating a set of baseline information on the presence and behavior of different types of fish in the Yukon, researchers hoped to anticipate potential impacts of the turbine on these species. The baseline data would also allow for a comparison of observed effects post-installation. To meet these research goals, the study was designed to sample fish at the margins of the river (away from the turbine) and in the center of the river (coinciding with turbine placement) to generate data on fish population, habitation, movement, and reaction to the turbine. This information would be necessary for both acquiring permits and assessing the impact of turbine placement on these existing populations.

Previous studies of fish communities were limited to the upper Canadian Yukon; similar information had not been collected for the Alaska Yukon near Eagle,[6] and there had been no sampling of the middle of the river channel in the Yukon for downstream migrating juvenile fishes.

Studies of the Upper Yukon in Canada highlighted the variety of fishes and behavior within individual sites. Bradford, Duncan and Jang acknowledged the complexity of the species composition and behavior, noting that "individual populations may have fidelity to specific habitats at various points in their life cycle and therefore may be affected by habitat impacts in those areas" (*Bradford et al.*). The understanding that fish species may be present in different abundances or exhibit different temporal or spatial patterns based on a specific river environment reinforced the need for a site-specific survey at Eagle.

The study at Eagle focused on the interaction between the turbine and the behavior of migrating juvenile fish. This was an important focus for two main reasons. First, there was a general lack of information on the community composition, migration patterns, and spatial distribution of juvenile fish within river channels in Alaska. For instance, the migration patterns of salmon can vary considerably from species to species and within different river habitats. Second, it was imperative to understand whether the Eagle turbine would injure or disturb juvenile fish, especially important species like chum and Chinook salmon, which were expected to be the most sensitive to any river disturbance, including hydrokinetic turbine activity. Based on the "assumption that out-migrating salmon fry (smolts) are likely to be in the fastest part of the river and therefore have the greatest potential to be impacted by this project," the SFOS environmental study focused on these juveniles' behavior under normal circumstances and their reaction to the turbine and on the development of a comparative index of river channel usage by juvenile fishes between margin and mid-channel habitats. (*Pilot Application 46*).

APT anticipated few adverse effects of the turbine on the more important species of fish. In the FERC application, which required a discussion of potential environmental impacts and methods to study these

[6] It should be noted that ADFG operates a sonar station about 6 miles downstream of Eagle for assessing the number of upstream-migrating adults (as part of the agreement with Canada), which likely use the river margins for upstream migration.

impacts, APT anticipated that adult salmon would stay in slower waters near river margins, be able to "detect a disturbance ahead and go around the turbine," or else be protected by trash racks and screens on the turbine (*Pilot Application 49*). APT also anticipated that whitefish would largely avoid the swifter currents in the middle of the river (turbine location) but if they did encounter the turbine, they would be protected by the turbine screens. Concern about the effect of the turbine on juvenile fish was generally mitigated by the prediction that smolt and fry of significant species would be small enough to pass near or even through the turbine uninjured (*Pilot Application 49-50*).

However, fish remain incredibly important to the livelihood of locals, who rely on them for subsistence, and to the commercial salmon fisheries elsewhere on the Yukon. Indeed, the principal goal of the Yukon River Salmon Agreement of 2001, between Canada and the United States, is "to rebuild and conserve stocks and provide benefits to the fisheries of both countries on this river system, which requires the maintenance in both countries of viable fisheries on the Yukon River;" an "agreed spawning objective" mandates that the U.S. ensure that fish reach the Alaska-Canada Yukon border. Of particular interest to the study, then, were the varieties of salmon in the stretch of the Yukon near Eagle. Researchers—and permitting agencies—were interested in evaluating the effect of the turbine on these species in particular. Chinook salmon smolts, for example, swim downstream in the fastest river currents; as this coincides with the location of the turbine (and potentially future turbines), assessing the effect of the turbine on these juveniles was a priority of this research.

Researchers gathered data from two types of sites within the river habitat near Eagle: the middle of the river (in the fast currents and behind the turbine) and the sides of the river (margins with slower current and shallower water). Researchers anticipated variation in fish concentrations and temporal patterns between these distinctly different habitats. The results from this study were compared to previous studies along the Canadian Yukon. Additionally, because fish presence and behavior can be influenced by environmental variables within a unique microhabitat, the study also collected data on a number of environmental variables at the Eagle site, including air and water temperature, quantity and type of visible debris, water velocity at given depths and distance from shore, turbidity, and river discharge.

The techniques used to collect fish samples were determined by the sample location. For the sites closer to the shore, researchers used reinforced fyke nets with wings to divert fish into the collection nets. These fyke nets were deployed six days a week for periodically scheduled sampling at different times of day (morning, afternoon, evening, and early morning/late night) at nine different sites. At four of these sites, collections were not possible at some point during the study because of river conditions or water level fluctuations. The remaining five sites were designated as primary sample sites as collections could be regularly performed there throughout the study. To sample the site in the middle of the river, researchers built a frame trawl and deployed it behind the turbine barge. The trawl was connected to the barge by a series of cables and winches that allowed it to be adjusted perpendicularly to the river current for optimal collection and was designed to gather information on the types of fish moving along the faster river currents and whether or not these fish were impacted/injured by the turbine. Unfortunately, this mid-river sampling could not be completed; because of the challenges faced during turbine deployment and operation, most notably the debris issues, the researchers were unable to carry out the planned sampling regimen, and this component of the study was not completed.

Results from the river margin sampling provided information on existing fish populations and community composition. The majority of fish caught were longnose suckers, Arctic grayling and whitefish. Chinook and chum salmon were also collected. This sampling provided some baseline information for species abundance at the margins closer to shore. Comparison to the studies on the Yukon near Dawson, Canada, revealed discrepancies between the relative population compositions, which researchers attributed to "several factors, including different sampling gear, microhabitat features of sampling sites, location specific characteristics of the fish community and interannual variation in the abundance of juveniles of each species" (*Bradley and Seitz*).

Researchers used the Eagle study samples—information on the number and size of fishes—to generate cursory characterizations of species' temporal patterns at the river margins. For example, researchers expected the Chinook salmon to "exhibit significant growth throughout the summer" because the juveniles feed and grow in the river for a year before their ocean migrations; this expectation "was supported by the increase in weekly mean length as the summer progressed" (*Bradley and Seitz*). On the other hand, because chum salmon do not remain in freshwater but head directly to the ocean, the researchers did not anticipate any definitive trend in size throughout the summer; this expectation was similarly supported by the study results from the river margins (*Bradley and Seitz*). The results also suggested that the composition of whitefish species and the overlap of specific species' individual development patterns create a complicated population dynamic.

The study also generated results that suggest that river conditions influence fish behavior. Because "each peak in catch rate [of longnose suckers] closely corresponded to a peak in river discharge," researchers believed that the movement of this species could be heavily influenced by environmental variables (*Bradley and Seitz*). This might suggest that other species could be similarly affected and that microhabitats (the unique combination of environmental variables at one specific site) can have a considerable impact on fish behavior. If turbines contribute to changes within these microhabitats, there could be effects down the road on fish behavior. Similarly, the discrepancies between observed fish population composition between the Eagle and Dawson studies on the Yukon suggest significant variation in fish presence and activity from site to site. This may be the product of any number of environmental or microhabitat factors; nevertheless, such variation would be significant when evaluating the potential fish impacts at a new, specific, or unstudied site.

This possible correlation between longnose suckers and river discharge highlights the value in being able to understand fish population and movement as a function of environmental conditions (including those caused by turbines or other equipment). If such variables can influence the type and behavior of fishes in an environment, understanding these relationships may help inform future knowledge of river habitats. The SFOS study gathered information on air and water temperature, amount and type of surface debris, water velocity, turbidity, and river discharge. General trends were observed for river turbidity, which increased through mid-August and then decreased through the season; discharge, which increased through mid-July and then began decreasing; and water and air temperature, which began decreasing towards the end of the season.

Analysis of the correlation between these observed environmental factors and corresponding fish patterns was completed by a SFOS master's student in the spring of 2012. This statistical correlation should contribute to knowledge about the interaction between fish and their environment, especially various microhabitat features. Developing this sort of insight into the factors affecting fish behavior might help characterize future turbine sites.

As with the overall project, this study faced a number of challenges over the course of the summer. Specifically, the problems with the turbine, including debris buildup, which required repair and maintenance, also prevented study samples from being collected at the middle-river site. These disruptions and limited access to the site prevented a "full characterization of the fish community in the middle of the river channel." Because of the uncompleted middle-river surveys, the SFOS research group was "unable to determine spatial patterns of downstream migrating juvenile fishes and evaluate impacts of a hydrokinetic turbine on downstream migrating juvenile fishes" (*Bradley and Seitz*).

As previously mentioned, the SFOS study gathered valuable information on fish abundance at the margins of the river but was not able to make any decisive observations about the behavior of fish in the middle of the channel. However, during a SFOS study conducted during the following summer, in 2011, samples were taken from the center of the river. These collections included numerous Chinook salmon smolts (juvenile salmon that have spent their first year growing in freshwater before heading downstream to the ocean saltwater). Because researchers did not catch any year-old Chinook smolts in 2010, the smolts' presence in the 2011 studies suggests that further exploration of the interaction between smolts and the hydrokinetic turbines will be necessary (*Seitz Interview*).

There are a number of potential outcomes of the smolt/turbine interactions. It is not clear whether these juveniles will be disturbed when traveling in the area of the river where the turbine is located, and there is concern that the turbine will directly injure the migrating fish and lead to juvenile salmon mortality. It is also possible, however, that the smolts will detect and completely avoid the turbine. Additionally, the smolts might be able to pass through the turbine uninjured. Because the leading edges of the turbine blades create higher pressure than the surrounding water, the smolts might be buffered aside by these pressure fronts and manage to pass through the turbine unharmed. These pressure differentials, however, might also endanger the fish by rupturing or damaging their swim bladders. Initial testing of the Eagle turbine suggested that turbine pressure differentials would not be harmful; however, testing in the real environment could not be completed (*Pilot Application 169*).

The Eagle fish studies reflected other complications with hydrokinetic turbines and their environment. That is, the studies illustrated the dynamic nature of river environments and the important role that various environmental factors can have on technical operations within a river. In particular, the SFOS study highlighted the potential for very specific fish behavior in response to microhabitat conditions—conditions that may vary widely. Indeed, it may be necessary to conduct thorough fish studies for all potential hydrokinetic sites, but these studies will be effort-intensive. As Bradford, Duncan and Jang note, "The vast scale of the landscape and the logistical difficulties of working in this region will continue to present considerable challenges to those attempting to develop a fuller understanding of the fish fauna of the Yukon River" (*Bradford et al.*). This observation is relevant to fish studies near hydrokinetic turbines within the Yukon, but it will apply to many other rivers as well.

Identifying the environmental factors that determine and influence fish species' patterns will contribute to addressing the "question of turbine-operation impacts on the aquatic environment [which] is one of the major issues that will determine stakeholder and permitting agency views toward this new technology" (*Johnson and Pride*).

Deployment and Performance

The Eagle project illustrated the exhaustive preparation necessary for the installation of hydrokinetic turbine technology, including the initial resource assessments, studies, and river characterization; the selection, design and engineering of various components, including the turbine and the transmission, conversion, anchoring, and deployment systems; the acquisition of and application for requisite permits;

and the contracting and/or design and implementation of the environmental and fish studies. The project also illustrated the unexpected challenges that can face deploying a new technology in a remote area.

Turbine Technology Selection

The initial project plan sought to install a single 100-kW UEK turbine, scaling up this system if the demonstration was successful. This first UEK turbine was being designed to site specifications during 2007–2008, with a delivery scheduled for the end of May 2009 (*4th Quarter, 2008*). Changes to the design of the turbine reflected the results of the bathymetric and velocity profiles characterizing the thalweg and identifying the fastest currents closer to the water surface. While the initial design favored a bottom-anchored turbine device, this was changed in order to access the swifter near-surface currents.

Unfortunately, the owner of UEK (and inventor of the UEK turbine) passed away in late 2008. Due to understandable delays expected from UEK arising from these circumstances, APT decided to contract another turbine provider to meet project and grant timelines. Eventually, APT procured a deal with the New Energy Corporation for its 25-kW EnCurrent vertical axis turbine. Fairbanks-based ABS Alaska, an alternative and renewable energy firm, would supply the turbine and provide hands-on turbine implementation and support (*2nd Quarter 2009*). Due to these changes in turbine selection, APT required more time for site specifications and engineering; the target deployment date was rescheduled for September 2009.

Ice Flooding

This adjusted plan, however, was interrupted by another challenge: ice. During ice breakup in the spring of 2009, an ice dam formed on the river close to Eagle. This ice dam caused the river to back up, which led to rising water levels along the Yukon near Eagle and at the turbine site. As water levels continued to rise, the river overflowed its banks. When the ice dam eventually ruptured, the already flood-stage waters rose even higher and carried the large fragments of the broken dam downstream. Carrying these enormous chunks of ice, water flooded the community and damaged existing power, transportation, and other infrastructure. APT's operation priority became the restoration of damaged utilities to affected residents. Rebuilding the community at Eagle required major resource investments. With tens of millions of dollars required for emergency response, relief, and community restoration, turbine deployment was inconceivable at that time. APT, ACEP, and the Denali Commission jointly decided to postpone installation until the next year, in the spring of 2010.

Final System Design

Design and engineering of the whole turbine system moved forward during the rest of the autumn of 2009 and the following winter. By 2010, the engineering and design for the turbine and the power conversion, anchoring, and deployment systems had been finalized (*1st Quarter 2010*).

A floating barge was constructed of double pontoons to house the turbine and provide a platform for operational maintenance. Deployed at the river surface, this turbine installation configuration allowed the vertical-axis device to be adjusted perpendicular to current velocities. The turbine could be raised out of the river for maintenance or repair and lowered into the water for operation. This orientation allowed for maximum power generation, and the assembly permitted personnel to perform basic operation and maintenance duties on the turbine, accessing the device from the barge.

Figure 3: 25-kW New Energy Corporation turbine, pictured here in the "raised" position, out of the water. When lowered by the barge mechanism, the turbine axis and blades (parallel to river in the image) would be positioned perpendicular to oncoming currents.

The method of securing a turbine may depend on the turbine's individual design—whether is it vertical or horizontal axis, bottom- or surface-mounted or an adjustable device—and must also take into account the physical characteristics of the site. The system employed at Eagle, an augmented deadweight anchor, was designed to meet the turbine barge's load-bearing requirements and work effectively given the riverbed's physical characteristics.

Specific elements of the river environment at Eagle were taken into consideration when selecting and designing the anchoring system for the New Energy Corp turbine. TerraSond's river studies, for example, characterized a "relatively smooth river bottom that was covered with close packed rocks to a depth of more than half a meter" (*International Water Power*). With this information, APT revised its initial plan, which called for a conventional penetrating anchor. Because of the rocky composition of the riverbed, this straightforward penetrating anchor would likely have been unable to properly secure the large deployment barge and turbine. APT decided to incorporate a deadweight anchoring system, which works, simply, "on the principle of being heavy" and is the method of choice for "rock, gravel, or coarse sand bottoms" (*INAMAR*). Two separate anchors would be arranged in line with the turbine barge to provide reinforced mooring.

Figure 4: The turbine anchor setup, with the two cement-block-and-fluke anchors (on the right) aligned with one another and the barge (left).

Each augmented deadweight anchor consisted of a penetration anchor with an added 36,000 pounds of steel-reinforced concrete to weigh it down (*Beste*). This design modification was necessary to secure the large barge necessary for the surface-deployed turbine; because the size of the barge would increase drag on the whole system, increased strength in the anchoring was needed to overcome the force of the river. APT built these two fluke anchors and strategized their arrangement and deployment.

Equipment was assembled and tested at ABS facilities in Fairbanks before river deployment. In May 2010, the equipment was disassembled and prepared for shipment to Eagle. Because of its excessive size and weight, the only way to transport this equipment was via trailer from Fairbanks to Eagle along the Taylor Highway. The equipment was delivered to Eagle by the third week of May, but before the crew could reassemble the shipped equipment and begin deployment, the project was again interrupted. Forest fires in the Eagle/Tok area required the evacuation of APT personnel. Turbine operations were again pushed back to later that summer.

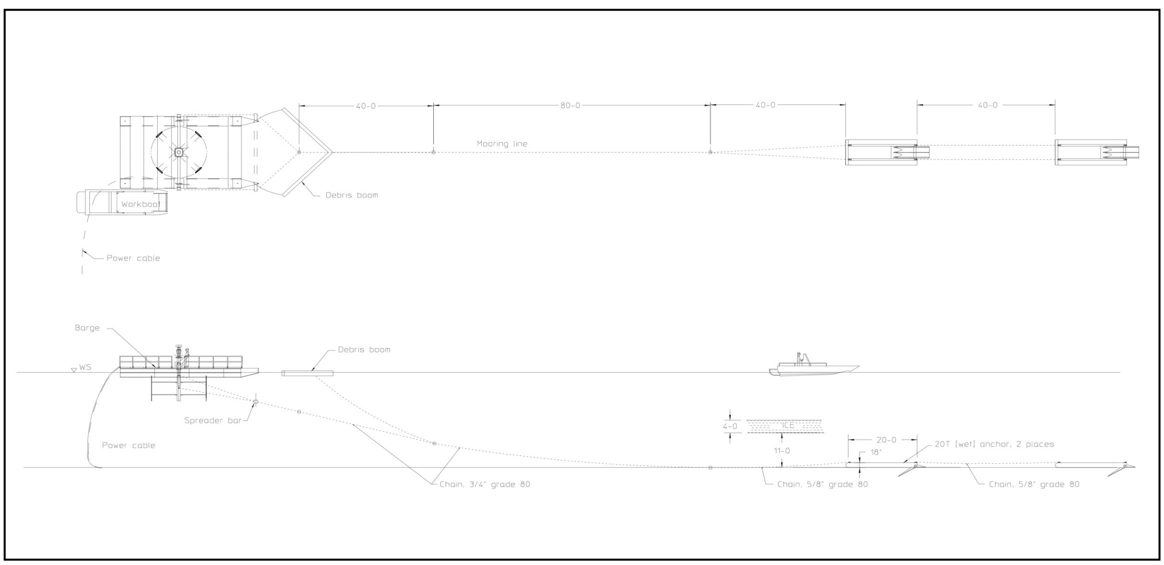

Figure 5: APT Diagram of turbine deployment schematic shows the positioning of the two anchors (right to left) and the debris diversion boom attached to the pontoon barge housing the turbine.

Deployment

Work at Eagle resumed by the beginning of June, and the team finished assembling the equipment and deployed the system. The anchoring system was deployed using a set of inflated airbags to float the heavy anchors into position. The anchors were released on a towline upstream and guided into position while the airbags were still inflated. These bags were deflated to sink the anchors into place. As the sunken anchors were pulled downstream by the current, the penetrating flukes fastened into the river bottom.

This method of installing such a large, heavy anchoring system was incredibly labor- and machinery-intensive.

Figure 6: One of the two concrete fluke anchors with inflated airbags to float them into place. Heavy machinery (like the CAT tractor pictured here) was required for this and other parts of the turbine system installation.

Each of the two anchors was subject to massive drag forces in the river currents. The crew launched the first anchor, attached to inflated airbags, from a public boat launch on a small back-eddy along the river upstream from the project site. While this seemed to be an advantageous place to launch equipment, the crew soon encountered the incredible difficulty of getting the anchor out of this back eddy and into the main channel currents, which were needed to float the anchor downstream. Because this first anchor was already situated in the eddy, the crew simply continued applying more and more force to it to move it. Finally, using essentially all the available horsepower at full force, the crew was able to get this anchor assembly into the main river current. The crew launched the second anchor from a beach rather than the boat launch. Several peronnel helped drag the anchor assembly and pull it out of the outside bend into the stream, against the prevailing current forces. This method was also difficult but more successful than the approach for the first anchor (*Beste Interview*).

The anchors were maneuvered into place using an anchor windlass, a winch typically used in marine applications for letting out and pulling in heavy equipment. The winch was able to position the anchors in their desired places parallel to the flow of the river; for moving an anchor laterally (along river transects), personnel were stationed on the island opposite the launch site and used lines to adjust the anchor position. This required the deployment of lighter lines from the anchor to the shore. Deploying light lines in the river, however, proved to be deceptively difficult; river forces exerted on lengths of even this thin line were significant and required substantial horsepower to overcome.

This setup was successful for positioning the anchors in their planned locations; however, the need for such heavy machinery and effort in deploying even light guidelines highlights the power requirements for in-river operations.

The turbine and barge were assembled together a mile from the site at the existing APT diesel power plant and driven on a trailer to the public boat launch on the river. The heavy assembly and equipment, however, overwhelmed the existing ramp and the trailer sank nearly up to its axle. Tractors and bucket loaders, as well as the personnel to operate them, were required to unstick the trailer. The crew had to reinforce the boat ramp before the assembly could be launched, devising specific equipment and methods to do so. This required shipment of gravel to Eagle that was used to solidify the silty ground at the launch area. This in itself was a time-consuming aspect of the deployment.

While many instructive lessons were learned during the installation of the anchoring system, the deployment of the turbine assembly was still an intensive process. The assembly was finally launched from the public boat ramp area upriver from the desired site with a combination of a hydraulically powered windlass winch and a series of workboats. The winch let out more than 2,000 feet of line as the motorized workboats guided the assembly into its operational position. The line used was high-strength polymer wool with a 50,000-pound load strength. The line held, but additional winch system features were required to back up the windlass winch as the river drag caused the loads to exceed expected amounts (*Beste Interview*).

Figure 7: The debris diversion boom is launched from the public boat launch using heavy CAT machinery and numerous personnel.

The windlass winch was useful for the longitudinal placement of the assembly, as it was the anchors, but additional finesse was required to get the assembly into the appropriate lateral position. A rudder that had been added to the barge to facilitate its positioning within the river proved to have very little discernable impact. The crew again used a series of lighter lines connecting the turbine to both shores to get the barge into position.

Again, using lighter lines for adjusting the barge proved difficult; two or three men were required to install, hold onto, and use each of these guide wires. Eventually, auxiliary pony winches were added to manage these lines (*Beste Interview*).

Figure 8: A laterally positioned winch operating on shore. The sheds housing the conversion/integration system and the BioSonics land-based equipment are to the right.

The barge was finally secured in place with reinforced mooring cables attached to the two anchors. The two attachment points for these mooring cables were located on the lateral sides of the barge; this design was advantageous in providing a symmetrical and neutral pivot point for the barge. However, this design also proved susceptible to debris lodging between the mooring lines and the underside of the barge (*Helmer*).

The entire deployment operation was an extremely lengthy process, requiring the use of several vessels and considerable labor. The inordinate manpower and horsepower necessary to get this assembly successfully installed speaks to the immense difficulty of coordinating any operations within a remote river setting. APT staff rehearsed their procedures beforehand, as mistakes made in the actual operations could potentially have costly and extremely dangerous consequences. This deployment faced some incredibly significant hurdles. While future iterations of the process became increasingly efficient as the crew were able to refine their techniques and equipment, the challenge of deploying a large or complicated system in the middle of a fast, powerful river current should not be dismissed. Many processes were incredibly time and labor intensive. The first deployment required 15–16 on-site personnel and took longer than anticipated to complete. Many smaller tasks were also tough; the effort involved in fixing the light guidelines, for example, was immense. Even the use of the sturdy winches, while offsetting the need for intense physical labor, required attentive operation and several crew members (*Beste Interview*).

Transmission and Integration

The successful use of hydrokinetic energy in offsetting fossil fuel consumption, as with many alternative sources of energy, including solar power and wind, requires the development of a reliable transmission and integration system to provide consistent and seamless electricity to existing utilities.

Though its limited production capacity (maximum of 25kW) would not have completely offset the need for diesel generation in the community, the Eagle turbine did generate electricity that was incorporated into the local grid with a customized integration system. As the utility provider, APT was committed to using this pilot project to investigate the potential for permanent turbine installation. Reliable transmission and integration would have to be an integral part of such a turbine system. Effectively transmitting and integrating turbine-generated electricity would allow this technology to realize its potential in offsetting the use of diesel fuel within the utility.

Delivering hydrokinetic energy onshore and using it within a rural utility grid requires a robust but adaptable system. The Ruby turbine deployment highlighted an important requirement of an effective transmission system within a river environment: a power cable connecting the turbine to on-shore operations must be long enough and strong enough to endure the forces exerted by a debris-laden river, and also easy enough to remove, readjust, and repair when necessary. During the first Ruby deployment in 2008, a transmission cable was simply laid across the bottom of the river. With the cable thus exposed to wear and tear, the river wore through it after only four days of operation (*Johnson and Pride 13*). The next summer, the project team employed a sturdier, heavier cable. The more durable cable, however, was extremely unwieldy, especially given the distance between the shore and the turbine (which had been increased so as to access swifter current). The team was unable to adjust or reposition the cable when they wanted to. Faster current was found further from shore, but accessing this current increased the size and design demands of the system.

The transmission and integration system at Eagle was composed of three main parts: (1) a component that included the generator assembly located on the barge, (2) a transmission line of armored power cable stretching from the shore to the turbine barge in the river, and (3) an on-shore power integrating system, capable of converting the variable frequency inputs from the turbine into three-phase, AC, standardized 60-Hz electricity output compatible with the Eagle utility grid (*2nd Quarter 2010*).

The transmission cable at Eagle fared significantly better than the one at Ruby, but it still highlighted the difficulty of reliably connecting a land-based station to a barge several hundred feet out in the middle of a powerful river. Early plans for the Eagle site explored the possibility of installing a cable connection with a directional bore (*Eagle Presentation*). Routing the cable through a bore would have served to protect the cable from the environmental wear that had posed a challenge at Ruby. Two different plans were put forward for the cable bore, both of which required extensive labor; both plans were prohibitively expensive. Given the generation capacity of a hydrokinetic turbine, drilling a directional bore was uneconomical (*Pilot Application*).

Instead, a custom-made, armored power cable was run perpendicular to the shore—and river current—directly to the turbine. Protective metal bands reinforced the three-phase conducting cables, which were encased within a PVC jacket. About 600 feet of this cable connected the turbine to the on-shore station. This length of cable was quite heavy but still required additional anchoring. Initially, the crew used 15-foot-long sections of the quarter-inch anchor mooring chain to weigh down the cable on the river bottom. These 75-pound chains, however, were not sufficient to secure the cable, so extra weight was added to the cable where it connected to the barge. Despite these measures, the force of the river lifted the cable from the bottom into the water column (*Beste, Helmer*).

Figure 9: Heavy chains being added to weight down the armored power cable.

The power cable was damaged twice during the summer for different reasons. Because there was initially insufficient anchoring weight on the cable, currents managed to lift the cable off the bottom and the sheering forces within the water column damaged this loosened cable. Fortunately, there was enough extra cable on site to redeploy after this first incident. Later on in the summer, however, debris buildup undermined the replacement cable. Because the cable had been oriented perpendicular to current, debris carried by the river became snagged on the line and could not readily be freed. The resulting accumulation of smaller debris (sometimes just pieces of moss) was sufficient to damage the cable connection. In fact, accumulated debris fragments increased the surface area of the cable—and, therefore, forces acting on the cable—to such an extent that the cable was nearly ripped cleanly off of the barge.

The generator assembly on the barge had been designed and built to take the lower hydrokinetic turbine speeds (~22 rpm) and increase them to the higher speed that the generator operated with (1,200 rpm) (*Beste*). This required a number of components, including a speed increaser shaft, and the initial design proved vulnerable to overheating. On shore, the power cable was tied into the existing grid by a conversion station designed and built by ABS, the turbine supplier. The conversion system included six power inverters designed to take the variable frequency inputs from the turbine power cable and provide a standardized 60-Hz output to meet load-side demands; this output could be alternatively supplied to the grid or to a standalone load.

The turbine began operating in mid-June 2010. Typically producing between 15 kW and 18 kW of electrical output, the turbine demonstrated that in principle it could convert the kinetic energy of the flowing current into electricity. However, problems with both the generation and the integration systems arose and compromised the ability to successfully use this electricity; an overheating transmission cable and the limited capability of the power conversion system both contributed to frequent outages. The solutions to these issues were not difficult to develop; however, the desire to keep the turbine in operation coupled with the difficulties of working in the river environment made these solutions difficult to implement.

The transmission problem was caused by the "over heating of the turbine generator transmission and subsequent outages caused by thermal overload trips" (*3rd Quarter 2010*). Fixing this overheating problem was pretty straightforward and simply required improvement to the transmission air-cooling system. The transmission on board the turbine barge needed a heat exchanger and oil circulation to remove excess heat from the speed increaser responsible for converting 22-rpm turbine speeds into much faster generator inputs. The integration unit also faced a relatively simple technical issue involving "power inverters supplied with [an] unacceptably narrow frequency excursion allowance, causing frequent nuisance generation outages" that resulted in only intermittent operation (*3rd Quarter 2010*). The solution to the converting unit was also pretty standard and only required replacement of the inverters with wider allowable frequency inverters (*Beste*).

Fortunately, the "solutions were quickly reached" for these two problem, (the transmission cable and the conversion system) and the system performed well once the components were improved (*3rd Quarter 2010*). The turbine was kept in service while equipment arrived and repairs were made although during this time it could only operate intermittently as the transmission system required regular cooling down periods. In addition, the transmission oil-cooling system added another component to the turbine barge assembly. Ideally, especially in rural applications, these systems would be simplified to eliminate potential technical problems or equipment failures. In this case, however, New Energy Corporation and APT staff determined that the additional equipment was necessary. There were no further issues for the rest of the summer (*Beste*).

The problems with the transmission power cable represent the inherent difficulty of doing work in Yukon River conditions. The immense forces exerted by moving water proved to be a major consideration in many aspects of this project, including the transmission cable. Orienting the cable perpendicular to the current, for example, was a significant design weakness.

Future installations will benefit from factoring these force considerations into their fundamental designs and reducing, as much as possible, the stress on the system by the environment. However, the power-generating principles of hydrokinetic turbines require that they be located in swift currents and important components of these devices are vulnerable to the forces and debris that accompany these currents.

Operations and Performance

Though delayed by environmental events and other extenuating circumstances, the turbine was fully installed and operational by mid-June 2010 (a year later than originally planned). In spite of a number of logistical setbacks, the turbine demonstrated the feasibility of hydrokinetic principles, successfully producing electricity from the free-flowing current in the river with a maximum output of 19 kW (*2nd Quarter 2010*).

Typical output during periods of successful operation ranged from 15–18 kW. The turbine could also provide a stand-alone system with a full 10 kW of 60-Hz electricity. Initially, this power output offered promise as a method of offsetting Eagle's diesel requirements by fulfilling a part of Eagle's daytime electricity demand and larger fraction of the community's nightly electricity demand during the summer. Theoretically, a larger set of turbines could offset diesel use completely during their operational months.

Indeed, APT had originally looked at the single turbine as a test of a potential larger system of several turbines. The current Eagle demand, which is between 60 kW and 160 kW, is filled by three 100-kW diesel gensets operating in a "one-on-full," "one-on-ready/standby," and "one-in-service" mode (*Beste Interview*). From the earlier calculations of river velocities, APT determined that winter operation of the hydrokinetic turbine would not be economically feasible and the community would rely on the conventional diesel gensets during that time, However, APT hoped that the hydrokinetic turbine system could eventually completely displace diesel use from May to September.

The best outputs from the test turbine supported this ambition. Indeed, the rated performance output of 25 kW could have offset a significant portion of diesel. Immediately after it was deployed—and before there were problems with the power cable and power conversion systems—the turbine performed according to design, generating electricity that could be integrated into the existing power grid. Optimal performance yielded 19 kW of power multiple times over the course of the turbine deployment.

An objective of the Eagle project was to provide an assessment of hydrokinetic turbine performance in real environments. Like other energy technologies, especially other renewable energy technologies, the efficiency of these devices is an important consideration in assessing their usefulness, productivity, and economic viability. Output, ranging anywhere from 12–19 kW, was below the rated output of 25 kW and was prone to fluctuation, suggesting that this turbine was operating below the maximum rated efficiency. Formal conclusions about the turbine's efficiency were precluded by (1) the difficulty in obtaining accurate, time-sensitive velocity measurements corresponding to turbine output and (2) the interruption of turbine performance by debris and other issues. Nevertheless, the turbine did produce significant usable electricity.

The optimism inspired by the turbine's peak performance, however, was soon dampened by the challenges of sustained turbine operation.

Debris

Though the project team was able to develop technical solutions to the initial problems with the transmission and integration systems, debris posed a much more chronic—and insurmountable—challenge. At the beginning of July, as the crew awaited the materials needed for fixing the transmission system, water levels began to rise. As debris was transported downriver, it interfered with the continued operation of the device.

The experience with debris at Eagle displayed the potential for debris to (1) directly damage essential equipment and (2) to accumulate on and endanger the turbine assembly.

Initially, the sheer extent of debris buildup disrupted turbine operation. Over a single night, during which the turbine was out of operation for cool-down, the barge assembly was completely swamped by debris, and it took a 12-man crew working for an entire day to clear it out. The original V-shaped diversion boom, basically a larger version of the one used at Ruby, was designed to deflect surface debris and protect the turbine from direct impact. However, this boom was not high enough to prevent debris from overwhelming it and accumulating on top of it. This boom was insufficient for managing the surface debris on the Yukon, which is capable of covering virtually the entire river (*Bradley and Seitz 15*). Additionally, because the boom projected from the front of the turbine barge assembly, the force exerted by the river currents on the boom caused the whole assembly to sway. This movement was dangerous for crewmembers on the barge and threatened the turbine barge assembly; because of this unforeseen danger, the boom was removed.

Following the removal of the boom, debris had to be removed from the turbine barge assembly manually. Debris inundated the barge during drift events, preventing turbine operation and requiring manual removal by numerous personnel stationed on the barge assembly. Workers often had to remove a protective grating over the turbine in order to access the device and remove entangled debris.

This process of manually removing all this debris was incredibly labor-intensive and, understandably, not a practical long-term solution. Ways to improve the existing mitigation equipment to deal with surface debris were explored.

The physical damage to the turbine assembly during this initial debris event prevented the system's return to service. While the turbine itself was visibly intact, the spreader bar component of the mooring system had been damaged. Subsurface debris had compromised this 20-foot-long, 2½-inch-wide straight steel pipe. Without this component, the turbine had to be taken out of commission. The assembly was disconnected from the transmission cable and brought to shore for repair while the spreader bar was replaced.

With repairs on the spreader bar underway, however, more river-borne debris damaged the transmission cable. At this point, both the cable and turbine barge were taken out of commission and removed from Eagle for repairs. Later in July, by the time both had been satisfactorily repaired and readied for redeployment, heavy rainfall forced the closure of the Taylor Highway, the only supply road to Eagle. With the repaired equipment at APT facilities in Tok, the turbine could not be placed back into service.

In August, nearly a month after the debris damage, the team finally put the turbine back to work. This required the redeployment of the barge and reconnection of the power cable/transmission system. The repaired equipment initially performed well upon redeployment. Because it was later in the season, the team did not anticipate any more significant increases in flow and expected the turbine to continue operating unhindered until scheduled removal in September.

However, less than two weeks later, another heavy debris incident damaged the system. Debris had breached the surface of and lodged underneath the barge. Because the roads were still largely impassable, a team had to be airlifted from the APT facility in Tok to Eagle to clear the debris. This three-person cleanup crew was able to clear the surface debris, but they were unable to assess or repair the damage to the assembly. Some of this damage was caused by subsurface debris that had become entangled in the transmission cable underwater. The cable tore off from the main assembly and the debris managed to work free, but the cable could not be recovered or repaired by the limited personnel on site. The team, however, decided to put the turbine back into operation for the duration of the season and SFOS researchers attempted to continue their scheduled fish studies.

In September, the turbine, power cable, and barge were removed for the winter. An additional six-man APT crew was dispatched to Eagle to retrieve and transport the turbine barge. Extensive equipment, including a series of winches and heavy CAT machinery, was required for this removal. Because the village was still accessible only at the Department of Transportation's discretion as it worked to repair the Taylor Highway, the crew was forced to work quickly between September 27 and 30. Equipment that required repair, such as the turbine generator, was shipped back to ABS facilities in Fairbanks, a process that required another two-man crew. Other equipment, including the barge and electrical equipment, was stored at Eagle over the winter. A great deal of labor and personnel was needed to complete the turbine extraction, retrieval, transport, and preparation for winter; given the difficulty in reaching Eagle along the Taylor Highway, this was a particularly significant requirement.

While "AP&T did not determine cost of the hydrokinetic energy," the experience at Eagle suggested that "actual operations and maintenance costs are variable and that extracting hydrokinetic energy is more involved than just how the turbine element interacts with the river environment" (*International Water Power 5).* While providing electricity from a hydrokinetic resource precludes the purchase and expense of fuel, "the cumulative associated costs for operating the hydrokinetic turbine at Eagle through the summer were very high resulting in a $/kWh that was many times greater than that for operating the diesel plant" (*International Water Power 5*). These inordinate operating costs motivated APT's decision to discontinue the project at Eagle.

Lessons Learned

The Eagle project was one of the first significant attempts at implementing hydrokinetic turbine technology in an Alaska riverine environment. With any new technology, it is the first prototypes that often face the biggest challenges; this was certainly the case in Eagle.

Hydrokinetic projects face a number of environmental and technical hurdles. The experience with the turbine at Eagle highlighted the extent of these hurdles and illustrated just how troublesome they may be to the success of this developing technology; it also illustrated the extent of some challenges, like drift events, which had not necessarily been fully understood by the parties involved beforehand (*Helmer Interview*). Identifying these hurdles and the lessons learned in the process, however, is an important step in improving hydrokinetic technology and allowing it to move forward.

The Eagle project illustrated the immense practical challenges that accompany the actual installation and operation of hydrokinetic turbine technology. Some of the challenges that arose were coincidental misfortunes, but other challenges proved to be intrinsic elements of this technology; these challenges, particularly debris and the difficulty of operating and maintaining mechanical equipment in fast river currents, were intractable obstacles for the turbine deployment in the summer of 2010. The project also proved to be extremely cost intensive. Expenditures for various aspects of the project—including the engineering, administration, permitting, site studies, project equipment, contracted equipment and operators, project construction and commissioning, daily operations, and extraordinary labor and operations—proved excessive.

In light of the cost of the turbine deployment, which were complicated by these various challenges, APT decided to pull operations out of Eagle. Together, APT, ACEP and the Denali Commission revised the original grant scope of work. As part of this revised plan, APT agreed to relocate the turbine and all equipment to Nenana, on the Tanana River, to be integrated into hydrokinetic research taking place at the Alaska Hydrokinetic Research Center turbine test site.[7]

The extent of the challenges faced in 2010 may have precluded turbine redeployment at Eagle for the summer of 2011, but the lessons learned from the experience can and should be applied to help inform future projects and research initiatives. Developing tested techniques and technologies for addressing these major issues will be imperative to the maturation of hydrokinetic turbine technology.

Indeed, the most general challenge for this technology may be the simple fact that it *is* developing. Many of the techniques and much of the equipment required for implementing hydrokinetic turbines are untested and certainly unperfected. There remains an extensive body of research to be completed on the interaction of these turbines with the environment; therefore, a discussion of lessons learned from the Eagle project will inform steps taken going forward and contribute to the development and improvement of this technology.

Understanding the Resource

In its early planning stages, the Eagle project demonstrated the importance of thoroughly understanding the environment in which this technology operates. Unlike conventional hydropower dams that alter the environment around them in order to produce energy, hydrokinetic turbines interact with the environment as it exists around them. The site assessments performed by TerraSond, for example, informed the eventual design for the turbine. The original UEK design for an underwater, bottom-based turbine allowed the height of the device to be adjusted within the water column in order to extract energy from the fastest currents available. The site surveys, however, determined that the fastest currents were, in fact, located near the river surface; this information made the advanced features of the original river-bottom turbine obsolete. Because each river environment is unique, understanding the environment is critical for selecting the appropriate turbine for a given site. There are many variations on turbine design, from the basic difference between vertical- and horizontal-axis devices to the more detailed distinctions between individual turbines. Selecting a device compatible for a given river requires an understanding of what the conditions in that river are.

A solid body of data for a given river locale is also important for proper placement of a turbine. In the first year at the Ruby test site, for example, the turbine was located too close to shore in currents insufficient to generate power. This problem could have been avoided with more data, such as velocity profiles. Locating optimal generation currents along a river site is just one of the reasons that information about the turbine environment is so crucial.

Understanding the effect that the environment might have on the turbine is a crucial part of designing and implementing a successful project. The TerraSond surveys, for example, allowed project managers to make knowledgeable decisions about several other important aspects of the turbine system. The

[7] Specifically, AHERC will continue the research efforts of the SFOS, evaluating the fish population and potential interaction of this population and a device located in the thalweg, and will investigate surface debris with a target of developing a surface debris device suitable for a barge-based device.

anchoring system was designed specifically for the rocky riverbed characterized by the site assessments. The unmodified penetrating fluke anchors that APT originally planned on utilizing would have been inadequate for the specific type of riverbed at Eagle; modified penetrating-weight anchors were required for the job.

Thorough site studies may be an extensive and perhaps expensive undertaking, and while these surveys alone do not guarantee a successful turbine installation, they are almost certainly requisite for one. They are important not only for selecting appropriate sites for turbines but also for generating an understanding and working knowledge of these sites.

As a technology that depends on the behavior of a given river at a specific location, hydrokinetic turbines may be susceptible to factors that affect river patterns and conditions. The dynamic nature of the river resource, though measurable at a given point in time through surveying and site assessment, is prone to change caused by outside forces. The need to resurvey the Yukon after the 2009 floods is one example of the need for regularly updated information on a turbine's environment. The equipment and expertise required for this kind of ongoing assessment will perhaps be extensive; though cost may preclude very detailed studies, establishing a solid baseline understanding of a particular river setting is absolutely imperative to inform turbine placement. Most of the techniques for river studies, such as bathymetric surveys and velocity profiles, are already well established, but more cost-effective methods—and timely delivery of results—could enhance the development and deployment of these turbines in Alaska and elsewhere.

Debris mitigation

Understanding the turbine's operational environment is critical for selecting and designing a system; this understanding alone, however, does not guarantee a turbine's flawless performance. The same principle that enables a hydrokinetic turbine to generate electricity with minimal environmental effect—i.e., allowing rivers to run unencumbered as the turbines extract energy—also makes these devices vulnerable to their environment.

These environmental challenges include debris and the general difficulty of working in a swiftly moving river. A constantly changing river environment can be dangerous; operating in a river requires the ability and flexibility to respond to expected and unpredictable situations. A number of uncontrollable factors can change a river's characteristics, including "water flow [that] can fluctuate dramatically on a seasonal basis depending primarily on the rate of seasonal snow and glacier ice melt" or the river's stability, evidenced by the ice jam flooding and devastation during the summer of 2009 (*Johnson and Pride 3*).

The Eagle project clearly illustrated the huge challenges that debris poses to current and future turbine installations. Without practical, effective and economical debris mitigation strategies, hydrokinetic technology cannot move forward.

Debris mitigation must address both the visible surface debris that can build up on the turbine barge and the unseen, neutrally buoyant debris that can become entangled in and compromise the subsurface components of the system, including the mooring and potentially the turbine itself. For example, the anchor mooring lines were prone to carry neutrally buoyant materials from the depths of the water column up onto the barge assembly. The initial deployment of the debris diversion boom prevented surface debris from directly impacting the turbine, but was eventually overwhelmed. The debris accumulation on the barge required extensive, labor-intensive, and potentially hazardous manual removal. Further testing of mechanical solutions and a more efficient use of personnel are needed to improve debris mitigation strategies.

Debris solutions will require a balance between effectiveness and cost. Manual removal of debris as it accumulates might be a necessary part of dealing with this issue, but it will probably be quite expensive and even dangerous (*Tyler 16).* The Eagle turbine demonstrated that manual removal of debris by personnel can be quite difficult, often requiring additional manpower and water vessels.

Other techniques for debris reduction might be explored, precluding the need for intensive manual debris removal operations. Such techniques might include using river geography to determine strategic locations for turbines where they might be less exposed to debris or where debris is less likely to float or accumulate. This would require a working knowledge of debris patterns, suggesting that further research about river debris could help with this type of prevention approach. A possible problem with this approach, however, is that locations less likely to receive heavy drift action are characterized by slower currents and, therefore, have less capacity to generate electricity. Because "the majority of debris travels in the thalweg," avoiding this debris would also mean avoiding the optimal generation currents (*Tyler 14*).

Other debris mitigation strategies used for in-river devices such as bridges or dams include trash racks, sweepers, and in-river installations to prevent debris from coming into contact with the downstream device. Many of these devices would likely be more economically difficult to implement in a hydrokinetic turbine setting. For example, trash racks are expensive and require regular debris removal; while economical for larger installations like dams, these devices would be too costly for use in smaller turbine projects, and debris accumulation on the racks would result in reduced power generation. Ideas for upstream devices to prevent debris from reaching the turbine during heavy drift events include "treibholzfange debris detention" installations, which incorporate an optimized configuration of posts driven into the river bottom to interrupt debris heading towards a specific site in the river. Placing turbines downstream from such installations might work to prevent overwhelming amounts of debris from reaching the turbine or barge. This technology has been tested at the Technical University of Munich but would probably require further trials before it could be reliably implemented (*Tyler 7*). Additionally, the construction of an effective treibholzfange would require an understanding of river flow patterns, the potential hydrodynamic effects of such a device, and debris drift characteristics.

Assessing the project outcome during 2010 deployment, APT planned to modify its debris boom in consideration of subsurface debris. APT planned on deploying a "float upstream of the turbine that would deflect the majority of the surface debris while providing a platform for personnel to reach and remove larger subsurface debris that becomes entangled in the mooring lines and collects on the turbine barge during debris movement periods" (*4th Quarter 2010*). To address the problem of the mooring lines directing debris up onto the barge, APT also planned on adding float lines to collect the debris upstream of the barge and facilitate its removal.

Debris severely undermined multiple aspects of the Eagle turbine project. Though APT and partners recognized that debris was a part of the river environment and took this into consideration, in many ways they expected it to be a nonissue (*Beste Interview*). This misconception quickly became apparent. APT not only learned the extent of the debris issue but also began to understand the ways in which this debris most impacted the turbine. For instance, though surface debris was "visually impressive" and built up on the barge, the biggest danger was really posed by the heavier subsurface debris (*Beste*). This massive, neutrally buoyant debris was often larger and more difficult to assess than the visual debris that accumulated on the barge. The submerged debris was hard to see and incredibly difficult to remove as it got caught on underwater cables or lines and even underneath the barge. For example, it required significant personnel to remove the 60-foot-long, 18-inch-diameter logs from under the barge, massive obstructions that the crew could not even see (*Beste*).

Debris mitigation will need to become an established area of expertise in hydrokinetic technology. It may be the area in greatest need of improvement for the technology to become reliable and truly mature. An otherwise economical hydrokinetic turbine project might be destroyed by debris in its early stages or taken out of commission for weeks at a time. For these turbines to become commercial and widely used, they will have to become financially advantageous over their fossil fuel alternatives. The potential devastation caused by debris will continue to make hydrokinetic turbines a risky investment unless reliable techniques for neutralizing debris damage are perfected.

Deployment

In early 2011, APT decided to discontinue the turbine project at Eagle, citing “higher than expected operating expenses” in 2010 as the main reason for this decision. To move forward with the project that year, APT anticipated that significant reduction in various aspects of the project would be necessary, including “cutbacks in activities such as the use of sonar monitoring” (1st Quarter 2011). No funding would remain to continue the project through 2012.

APT’s experience at Eagle, that “labor forces necessary to maintain the turbine equipment were by far the highest expense,” highlights that the unusually high costs associated with maintaining a hydrokinetic turbine, particularly in the development stage of the technology, may pose a significant obstacle to its installation (*1st Quarter 2011*). In Eagle, a considerable added expenditure was required for transporting necessary personnel to the site when crises emerged. The excessive buildup of debris, for instance, required more manpower than had been anticipated.

Aspects of the Eagle project that were particularly labor-intensive included (1) installation, (2) maintenance and debris management, and (3) removal. The turbine installation, for instance, required a crew of 10–12 people plus additional technicians and equipment operators for the first deployment. Significant personnel were also required for maintaining the device, repairing or replacing various parts of the system, and dealing with debris. While daily operations fell under the purview of the Eagle APT staff of two men, a number of extraordinary circumstances—like repair, replacement, and heavy drift events—required the use of additional labor. In the case of emergency maintenance and repair, many of these workers had to be quickly transported to the site, sometimes airlifted in. Not only did this increase the labor costs of the project, but also it illustrated that the availability of adequate, capable personnel is extremely important for these devices. This was particularly true since the manual debris mitigation strategy required on-site personnel to remove debris from the turbine assembly.

Remote Location

The experience at Eagle illustrated the challenge of coordinating a successful hydrokinetic project in a remote location. A number of environmental factors delayed turbine equipment transport and deployment, including forest fires and flooding. On the one hand, these conditions were unfortunate coincidences in the summer of 2009 and 2010. On the other hand, while this technology is supposed to be a promising energy resource for isolated rural communities, these events show the extent of the difficulty in installing and operating a turbine in exactly this sort of rural community. The isolated nature of the

Alaska communities in which these turbines would ideally be deployed presents a number of challenges related to device and equipment transportation, maintenance, and installation/removal.

The Eagle project demonstrated the considerable costs of transport and assembly required for the size and variety of turbine equipment at that location. Manufactured and tested offsite, the turbine equipment had to be brought to Eagle. Theoretically, the transportation of the equipment to Eagle via the Taylor Highway should have been relatively straightforward; instead, it was frustrating and difficult. For similar remote communities—or communities with no road access at all—transportation of turbine materials must become easier and more streamlined.

The Eagle project faced additional challenges when the turbine assembly was overwhelmed by debris in early July; these challenges were significantly complicated by Eagle's remote location. The arrival of repair materials was delayed for several weeks because of closures to the Taylor Highway caused by floods. When debris again damaged the turbine later in the summer, the three-man crew had to be airlifted to Eagle because of this highway closure. Additionally, personnel on site could not fix the damage to the power cable and reinforcements were unavailable. Because remoteness is an inherent trait of the communities that these turbines are supposed to serve, some method of mitigating the challenge of accessing rural location must be developed. Perhaps this will require more equipment stored on site to preclude delays while waiting for parts to arrive. Or it might mean a simplification of turbine maintenance to enable laymen to perform basic repairs, upkeep, and debris removal.

The installation and removal of the turbine and the periodic mechanical upkeep of the device were also complicated by Eagle's remoteness. The rigorous installation process required bringing in additional personnel and a variety of heavy machinery. These personnel and equipment might not be available in all communities; multiple winches and boats might not be on hand for installing turbines everywhere they might be useful. In September, a sizable team had to be sent to Eagle for removal of the turbine and preparation for winter storage.

In general, coordinating the appropriate gear and manpower for this project was made more difficult by Eagle's remoteness. Because other isolated communities will likely face similar difficulties, the development of this technology must include strategies that minimize labor requirements and that facilitate the process of obtaining replacement materials and implementing repairs.

Riverine Environment

Understanding the river environment is an integral part of selecting and siting a hydrokinetic turbine; the ability to work within the river environment is an integral part of implementing and operating a turbine. The characteristics of a fast-flowing river environment—the type of location where this technology could be useful—complicate these projects. In Eagle, the river environment complicated essentially every task related to turbine installation, maintenance, repair, and removal.

Figure 10: Workboat and personnel during turbine deployment.

Working in a flowing river was a very real physical challenge for the turbine crews. Workers performing tasks in the river had to compensate for the force exerted by the current on all their equipment, boats, wires, and lines. Even straightforward tasks, like running lengths of thin guidelines to assist turbine deployment became incredibly challenging, requiring atypical amounts of power. Using multiple workboats to accomplish tasks became necessary, but it was dangerous. Working in the Yukon required extra power and extra safety precautions for nearly all procedures. The crews had to devise new approaches to operate in this river setting or, when necessary, simply increase the force at their disposal or the manpower applied to a task.

Not only did the river environment complicate turbine-related operations and require more labor and manpower than was anticipated, it also increased the stress placed on the actual turbine system, which caused many of the performance issues throughout the summer. The failures of the transmission power cable, for example, resulted from sheer forces of the river currents and the accumulation of river-borne debris. The various components of the system had to be durable enough to withstand the environmental forces of the river but also easy enough to implement, adjust, and repair.

Moving Forward

There remain a number of significant barriers to commercial deployment of hydrokinetic turbines in Alaska rivers, including knowledge gaps, engineering challenges, and permitting considerations. While this project did not successfully overcome many of these barriers, it further refined understanding or otherwise highlighted their importance, including the following:

- Environmental interaction, in particular debris but also sediment and fish interaction
- Site characterization, including hydrodynamic conditions and local factors affecting deployment, operations, and maintenance
- Technology considerations for the targeted environment, including deployment, operation and maintenance strategies, system component design and performance, and overall system performance
- Governmental and regulatory considerations, including permitting and stakeholder engagement

The primary recommendation of this report calls for an incremental and strategic approach to research that supports hydrokinetic technology development efforts in Alaska. In order to be successful, a tiered approach to technology development and demonstration must be matched by a similar incremental approach to overcoming the knowledge gaps and engineering challenges, especially those associated with environmental interaction and site characterization. Such an approach has been incorporated into the strategic plan and research efforts of AHERC, resulting in significant progress regarding site characterization techniques and surface debris characterization and mitigation (*AHERC*).

The second recommendation of this report calls for a strategic statewide approach regarding the development of hydrokinetics in Alaska. Alaska has tremendous potential for hydrokinetic technology development and deployment. There are many projects, activities, and organizations (including technology developers, support companies, government entities, and universities) that are focused on hydrokinetics. There has been little success, however, in terms of deployment, operations, and maintenance of a device. The barriers to hydrokinetics are daunting and complicated, requiring a coordinated effort to be successfully overcome. Many of the barriers, for example, are universal to hydrokinetic projects regardless of specific technology; a joint approach by developers, in cooperation with the university and state, could allow for the successful development of solutions.

Works Cited

Alaska Hydrokinetic Energy Research Center. "Draft Strategic Plan 2010-2013." AHERC online, Web. July 2011. http://www.uaf.edu/files/acep/2010_10_24_AHERC_Strategic_Plan.pdf

Alaska Energy Authority. "Hydroelectric." *Renewable Energy Atlas of Alaska*. May 2009. **p 10**

Alaska-Pacific River Forecast Center. "Ice Break-Up Reconnaissance in Alaska." Web. Aug 2011. http://aprfc.arh.noaa.gov/resources/docs/brkup.html

Alaska Power & Telephone. "Yukon River Hydrokinetic Turbine Project, Eagle, Alaska: Minor Water Project, Draft Pilot Project License Application." 5 Feb 2008

---. "Eagle Hydrokinetic Turbine Project," Presentation, Alaska Tidal Energy Conference, Jan 2007. Web. July 2011. www.aptalaska.com/upload/ppt/eagle.hydrokinetic.turbine.080707.ppt

"Attachment A: Statement of Services." UAF Professional Services Contract 10-0054. University of Alaska Fairbanks and Alaska Power & Telephone. 5 Feb 2010. **p 9**

Beste, Ben. APT. Interviews, 25 July 2011; 11 Aug 2011

BioSonics. "Case Studies and Applications: Rivers Hydrokinetic Environmental Monitoring," BioSonics On-line, http://www.biosonicsinc.com/matrix_nodes.cfm?step=2&row_id=13&col_id=3

---. "Hydroacoustic Monitoring at the AP&T Hydrokinetic Turbine Project, Eagle, Alaska, 2010." 30 Mar 2011. **p 1**

---. "What is HydroAcoustics?" BioSonics On-line. Web. Aug 2011. http://www.biosonicsinc.com/resources-what-is-hydroacoustics.asp

Black, Robert, Bruce McKenney, and Robert Unsworth. "Introduction and Summary, Chapter 1." Prepared for U.S. Fish and Wildlife Services. *Economic Analysis for Hydropower Relicensing Projects: Guidance and Alternative Methods*, http://www.fws.gov/policy/hydrochap1.pdf. **p 1-3**

Bradley, Parker T., and Andrew C. Seitz. "Characterization of the juvenile fish community in the upper Yukon River near Eagle, AK." School of Fisheries and Ocean Sciences, University of Alaska Fairbanks.

Carlton, Jim. "Spring Thaw Triggers Damaging Floods in Alaska." WSJ Online. 8 May 2009. Web. Aug 2011. http://online.wsj.com/article/SB124173392622498125.html

Chu, Keith. "US House committee passes bills to speed renewable energy permitting." 13 July 2011. http://www.platts.com/RSSFeedDetailedNews/RSSFeed/ElectricPower/6275931

"Chunks of floating ice tear up Alaska town." MSNBC.com. 7 May 2009. Web. Aug 2011. http://www.msnbc.msn.com/id/30619771/ns/weather/t/chunks-floating-ice-tear-alaska-town/

Denali Commission Project Database System. "At-a-Glance for Alaska Power Company Project #313-07, Eagle: Hydrokinetic Turbine Project." Alaska Energy Cost Reduction Program Progress Reports: *2nd Qtr 2008; 4th Qtr2008; 2nd Qtr2009; 3rd Qtr2009; 4th Qtr2009; 1st Qtr2010; 2nd Qtr2010; 3rd Qtr2010; 4th Qtr2010; 1st Qtr2011*. Web. July/August 2011. https://www.denali.gov/dcpdb/index.cfm?fuseAction=IndicatorDisplay.ProjectAtAGlance&filterfieldvalue=92

Fay, Ginny, Alejandra Villalobos Meléndez, Ben Saylor and Sarah Gerd. *Alaska Energy Statistics*. Prepared for Alaska Energy Authority. Institute for Social and Economic Research. May 2011. http://www.iser.uaa.alaska.edu/Publications/AlaskaEnergyStatistics2011.pdf

Federal Energy Regulatory Commission. "Licensing Hydrokinetic Pilot Projects: FAQs." 14 April 2008. Web. July 2011. http://oregonocean.info/index.php?option=com_docman&task=doc_view&gid=36&Itemid=19

---. "Preliminary Permits." 4 Aug 2011. Web. 24 Aug 2011. http://www.ferc.gov/industries/hydropower/gen-info/licensing/pre-permits.asp

Golden Valley Electric Association. "Golden Valley Electric Association: Tanana River Hydropower Scheme; Tanacross, Alaska, Reconnaissance Study." GVEA Renewable Energy Pledge and Potential. Jan 2009. Web. July 2011. http://www.gvea.com/energyprograms/

---. "Golden Valley Electric Association: Nenana River Hydropower Scheme; Healy, Alaska, Reconnaissance Study." GVEA Renewable Energy Pledge and Potential. Jan 2009. Web. July 2011. http://www.gvea.com/energyprograms/

Helmer, David, APT Staff in Eagle. Interview, 18 August 2011

Hirsch, Brian and Monty Worthington. "In-Stream Hydrokinetic Turbine in Ruby, Alaska." Presentation. Bureau of Indian Affairs Tribal Service Providers Conference. 4 Dec 2008. Web. Aug 2011. www.yritwc.org/Portals/0/PDFs/BIA-12-08.pdf

Holdmann, Gwen and Bob Grimm. "Rescope Proposal, AP&T Eagle In-River Hydrokinetic Project." Letter to Denali Daniels. 3 Mar 2011.

Hydropower Reform Coalition. "Protecting Shorelands as Part of the Hydroelectric Relicensing Process." http://www.hydroreform.org/hydroguide/shorelands/2-1-federal-power-act

INAMAR, Recreational Marine Insurance, "Moorings: Important recommendations for safe moorings from INAMAR," Web. Aug 2011. http://ocw.tudelft.nl/fileadmin/ocw/courses/OffshoreMoorings/res00027/Moorings.pdf

Johnson, Jerome B. and Dominique J. Pride. “River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska.” Prepared for the Alaska Energy Authority by the Alaska Center for Energy and Power. 1 Nov 2010. http://www.uaf.edu/files/acep/2010_11_1_State_of_the_Art_Hydrokinetic_Final.pdf

Kassam, Shamez. “In-Situ Testing of a Darrieus Hydro Kinetic Turbine in Cold Climates.” Thesis. University of Manitoba Department of Mechanical and Manufacturing Engineering. 2009. Web. July 2011. home.cc.umanitoba.ca/~bibeauel/research/thesis/2009_Kassam.pdf
Appendix C

Martin, Glen. "Eagle." Correspondence with Author. 24 Aug. 2011. E-mail.

Michael J. Bradford, Jake Duncan and Jean W. Jang. “Downstream Migrations of Juvenile Salmon and Other Fishes in the Upper Yukon River.” *Arctic*, Vol. 61, No. 3. Sept 2008. Arctic Institute of North America. Web. Aug 2011. **p 256**

National Renewable Energy Laboratory. “NREL’s Wind R&D Success Stories.” U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Website. Jan 2010. Web. 21 Aug 2011, www1.eere.energy.gov/windandhydro/pdfs/46635.pdf

---. “20% Wind Energy by 2030: Increasing Wind Energy’s Contribution to U.S. Electricity Supply.” July 2008. Web. Aug 2011. www.nrel.gov/docs/fy08osti/41869.pdf

Olsen, Stephen Bloye and Glen Ricci. “Essential Fish Habitat.” 3 Aug 2011. Web. Aug 2011. http://www.coastalwiki.org/coastalwiki/Essential_Fish_Habitat

Previsic, Mirko. “EPRI RP 006 Alaska: System Level Design, Performance, Cost and Economic Assessment – Alaska River In-Stream Power Plants.” Electric Power Research Institute. 31 Oct 2008.

Ryan N. Tyler. “River Debris: Causes, Impacts, and Mitigation Techniques.” http://acep.uaf.edu/media/89662/2011_4_13_AHERC-River-Debris-Report.pdf

Seitz, Andrew. School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Interview, 9 August 2011

State of Alaska Department of Community and Economic Development. “Community Database Online: Eagle.” Web. Aug 2011 http://www.commerce.state.ak.us/dca/commdb/CF_BLOCK.cfm?Comm_Boro_Name=Eagle&Data_Type=generalOverview&submit2=Get+Data

TerraSond. “Reconnaissance Survey for Hydroelectric Turbine Sites: Yukon River, Eagle, Alaska.” Prepared for Alaska Power & Telephone. 31 Oct 2007. Included in *Yukon River Hydrokinetic Turbine Project, Eagle, Alaska: Minor Water Project, Draft Pilot Project License Application*.

“Tidal and River Hydrokinetic Energy Development in Alaska.” *International Water Power and Dam Construction Magazine*

U.S. Army Corps of Engineers. “River Ice Network Mission Statement.” Web. Aug 2011, http://www.mvp-wc.usace.army.mil/ice/mission.html

U.S. Coast Guard. “Offshore Renewable Energy Installations (OREI).” 6 April 2011. Web. Aug 2011. http://www.uscg.mil/d17/d17%20divisions/dpw/OREI.asp

U.S. Department of Energy Group Paper: M. J. Sale; G. F. Cada; L. H. Chang; S. W. Christensen; S. F. Railsback; J. E. Francfort; B. N. Rinehart; G. L. Sommers. “Environmental Mitigation at Hydroelectric Projects, Volume 1., Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage.” Dec 1991. **p v-vi**

U.S. Department of Energy: Energy Efficiency and Renewable Energy. “Types of Hydropower Plants.” *Wind and Water Power Program: Technologies*. Web. 8 Aug 2011. http://www1.eere.energy.gov/windandhydro/hydro_plant_types.html

---. “History of Hydropower.” *Wind and Water Power Program: Technologies*. 11 Nov 2008. Web. 8 Aug 2011. http://www1.eere.energy.gov/windandhydro/hydro_history.html

U.S. Geological Survey. “Environmental and Hydrologic Overview of the Yukon River Basin, Alaska and Canada.” *Water Resources Investigations Report* 99-4204, 2000. qtd in “Yukon River Hydrokinetic Turbine Project, Eagle, Alaska: Minor Water Project, Draft Pilot Project License Application”

Yukon River Inter-Tribal Watershed Council. “Ruby Hydrokinetic Electrical Generation Project Fish Monitoring Pilot Study Work-plan, Summer 2009.” Web. Aug 2011. http://www.akenergyauthority.org/OceanRiver/SF2009-160a-2study%20plan.pdf

“Yukon River Hydrokinetics.” Alaska Center for Energy and Power. 6 Jul 2010. Web. July 2011. http://acep.uaf.edu/programs/data-collection-management/projects.aspx

“Yukon River Salmon Agreement of 2001.” http://yukonriverpanel.com/salmon/wp-content/uploads/2009/02/yrs-agreement.pdf